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The 2014 assessment of the snow crab (*Chionoecetes opilio*) stock in the southern Gulf of St. Lawrence (Areas 12, 19, 12E and 12F)

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

The 2014 assessment of the southern Gulf of St. Lawrence (sGSL) snow crab, *Chionoecetes opilio*, stock (Areas 12, 19, 12E and 12F) is presented. Snow Crab management Areas 12, 19 12E and 12F comprise a single biological population and the sGSL stock is considered as one unit for assessment purposes. The 2014 assessment was conducted as per the recommendations of the Snow Crab Assessment Methods Framework Science Review held in November 2011. The exploitation rate of the 2014 fishery in the sGSL was 37.1%. The 2014 post-fishery survey biomass of commercial-sized adult male crabs was estimated at 67,354 t (95% confidence intervals 60,994 to 74,579 t), an increase of 2.5% from 2013. The available biomass for the 2015 fishery, derived from the 2014 survey, is within the healthy zone of the PA Framework. The residual biomass (23,897 t) from the 2014 survey decreased by 11.1% compared to 2013. Sixty-five percent (65%) of the 2014 survey biomass, available for the 2015 fishery, is composed of new recruitment (43,630 t). The recruitment to the commercial biomass from the 2014 survey increased by 11.9% relative to the previous year. The predicted recruitment of commercial-sized adult male crab for the 2016 fishery was estimated at 42,300 t (32,760 to 51,840 t). A risk analysis of catch options for the 2015 fishery is provided.

RÉSUMÉ

L'évaluation de stock du crabe des neiges, *Chionoecetes opilio*, du sud du golfe du Saint-Laurent (sgSL) de 2014 est présentée (zones 12, 19 12E et 12F). Les crabes des neiges des zones de gestion 12, 19, 12E et 12F font partie d'une seule population biologique, et le sgSL est considéré comme une unité aux fins d'évaluation. L'évaluation de 2014 a été effectuée selon les recommandations suite à l'examen cadre des méthodes d'évaluation du stock de crabe des neiges dans le sgSL tenu en novembre 2011. Le taux d'exploitation pour la pêche de 2014 dans le sgSL était de 37,1%. Selon le relevé effectué après la pêche de 2014, la biomasse de crabes adultes de taille commerciale a été estimée à 67 354 t (intervalle de confiance de 95%, 60 534 t à 74 579 t), une augmentation de 2,5% par rapport à 2013. Le niveau de la biomasse pour la pêche de 2015, provenant du relevé de 2014, se situe dans la zone saine du cadre de l'approche de précaution. La biomasse résiduelle (23 897 t) estimée à partir du relevé de 2014 a diminué de 11,1% par rapport à 2013. Soixante-cinq pourcent (65%) de la biomasse du relevé de 2014 exploitable pour la pêche de 2015 est composée de nouvelles recrues (43 630 t). Le recrutement à la biomasse commerciale estimé à partir du relevé de 2014 a augmenté de 11,9% par rapport à l'année précédente. La prédiction du recrutement des mâles adultes de taille commerciale pour la saison de pêche de 2016 a été estimée à 42 300 t (32 760-51 840 t). Une analyse de risque sur les options de captures pour la saison de pêche de 2015 est fournie.

1.0. INTRODUCTION

Snow crab, *Chionoecetes opilio*, has been commercially exploited in the southern Gulf of St. Lawrence (sGSL) since the mid-1960s. Until 1994, the snow crab fishery in Area 12 (Fig. 1) was exploited by 130 mid-shore crab harvesters from New-Brunswick, Québec and Nova-Scotia. In 1997, the Prince Edward Island coastal fishery, (formerly called Areas 25/26) was integrated into Area 12. In 2003, a portion of the coastal fishery off Cape Breton (formerly called Area 18) was also integrated into Area 12 and a northern part of Area 18 was set as a buffer zone (non-snow crab fishing zone, label B in Fig. 1). For the purpose of this assessment, Area 12 refers to the new management unit (Fig. 1). In 1978, Area 19 (Fig. 1) was established for the exclusive use of Cape Breton inshore crab harvesters with vessels less than 13.7 m (45 feet) in length. Areas 12E and 12F were introduced in 1995 as exploratory fishery areas. A two nautical mile buffer zone was created between Area 12F and the adjacent Area 19 in 1996 (label B in Fig. 1). In 2002, the status of these fishing areas was changed from exploratory to commercial.

Currently, there are four individually managed fishing areas (Areas 12, 19, 12E and 12F) (Fig. 1), with Area 12 being the largest in area, number of participants, and landings. There is no biological basis for the delimitations of snow crab management areas in the sGSL (Chiasson and Hébert 1990; Hébert et al. 2008; DFO 2009). Crabs in these management areas are considered part of a single biological population and the sGSL is considered as a single unit for assessment purposes (Hébert et al. 2008).

Management of these fisheries is based on quotas (by management area and distributed among license holders) and effort controls (number of licenses, trap allocations, trap dimensions, and seasons).

In Areas 12, 12E and 12F, the fishing season generally starts as soon as the sGSL is clear of ice in late April to early May and lasts either until the closure of the fishing season in mid-July or when the quota is caught. In Area 19 the fishing season starts in July and ends in mid-September or when the quota is caught. The landing of females is prohibited and only hard-shelled males ≥ 95 mm carapace width (CW) are commercially exploited. Different limits on the number of traps apply to each license depending on the group and fishing area.

New management measures were introduced in 1990 following the early closure of the Area 12 fishery in 1989 due to a rapid decline in catch rates and high incidence of soft-shelled crabs in catches. One of the measures was to set the total allowable catch (TAC) or quota as some proportion of the biomass of adult male crab ≥ 95 mm CW, as estimated from a trawl survey. Another management strategy, applied to maximize yield and reproductive potential by limiting the capture of soft-shelled males, was to close portions of the fishery based on the percentage of soft- or white crabs.

This assessment follows the recommendations from the Framework Science Peer Review of stock assessment methods for the sGSL snow crab stock held on November 21-25, 2011 (DFO 2012a). This report presents the assessment and commercial biomass estimates for the 2015 snow crab fishery in the sGSL (Areas 12, 19, 12E and 12F). Biomass estimates and population characteristics by life stage are derived from a trawl survey conducted after the fishery covering the sGSL snow crab habitat. Risk analysis of catch options for the 2015 fishery relative to the commercial biomass and removal reference points is also presented.

2.0. SYNOPSIS OF SNOW CRAB BIOLOGY

In the sGSL, molting of snow crab occurs from December to April, prior to the fishery (Watson 1972; Conan et al. 1988; Sainte-Marie et al. 1995; Benhalima et al. 1998; Hébert et al. 2002).

Crab normally molt annually until they reach the adult phase via a final or "terminal" molt (Conan and Comeau 1986). Males reach adulthood at sizes ranging from 40 to 150 mm CW and females at 30 to 95 mm CW (Conan and Comeau 1986). Estimates of longevity of adult males are (after reaching the terminal molt) between 5 (Sainte-Marie et al. 1995) and 8 years (Fonseca et al. 2008).

In contrast to immature females, pubescent (adolescent) females have a wider abdomen and fully developed orange gonads in the fall. These females then undergo a terminal molt between December and April and become nulliparous females having a fully enlarged abdomen and ripe ovaries. Generally, they mate immediately after molting, while their carapace is still soft, and then extrude fertilized eggs for the first time, becoming primiparous females (Watson 1969; Moriyasu and Conan 1988). Multiparous refers to females which are repeat spawners (second brood or more). Their mating season occurs from late-May to early-June, after their eggs have hatched (Conan and Comeau 1986; Moriyasu and Conan 1988; Sainte-Marie and Hazel 1992; Moriyasu and Comeau 1996; Sainte-Marie et al. 1999). Mature females normally carry their eggs under the abdomen for two years in the sGSL (Mallet et al. 1993; Moriyasu and Lanteigne 1998), while a negligible portion of mature females follow a one-year cycle in Baie Sainte-Marguerite (Sainte-Marie et al. 1995). However, Khun and Choi (2011) reported that over 80% of mature females were estimated to follow a one-year reproductive cycle on the Scotian Shelf.

Mature females, both primiparous and multiparous, may produce more than one viable brood from sperm stored in their spermathecae from the first mating, without any subsequent mating (Sainte-Marie and Carrière 1995). However, the probability that a single mating is sufficient to fertilize a female's lifetime production of eggs has been shown to be low (Rondeau and Sainte-Marie 2001). Mating after egg hatching seems to be a general rule for snow crab in the sGSL (Conan et al. 1988).

After molting, crabs have a soft shell engorged with water. It takes about 8-10 months for the carapace of an adult soft-shelled male to harden (Hébert et al. 2002) and one year to attain maximal meat yield (Dufour et al. 1997). Adult soft-shelled males are not able to mate during their postmolt period, but become active in reproductive activities with nulliparous females in February of the following year and in May-June with multiparous females (Conan et al. 1988; Moriyasu et al. 1988). Adult soft-shelled males of legal size represent the annual recruitment to the fishery, as they become commercially marketable in the following fishing season (Conan and Comeau 1986; Sainte-Marie et al. 1995; Comeau et al. 1998a; Hébert et al. 2002). Following Sainte-Marie et al. (1995), we use the term "adolescent" and "adult" to refer to what was formerly called morphometrically immature and mature, respectively (Conan and Comeau 1986).

3.0. METHODS

3.1. TRAWL SURVEY BIOMASS ESTIMATION

There have been progressive changes in the sampling design and protocols of the sGSL trawl survey since its inception in 1988. Originally, the survey area was sub-divided using a lattice of 10 by 10 minute latitude-longitude grids. One or two sampling locations were then randomly selected and used as fixed stations in subsequent survey years. Initially, the survey area only covered Area 12 but was expanded to Area 19 in 1990. Area 12 was sampled before its fishery (July to October) for all years (except 1996 where there was no survey) and Area 19 was sampled before its fishery from 1990 to 1992 and then after its fishery from 1993 onward (Moriyasu et al. 2008).

In 1997, the survey area was again extended to include the new management Areas 12E and 12F. New stations were added randomly within grids as the survey expanded or if areas were targeted for more intensive sampling. Further details of these survey design changes are provided by Moriyasu et al. (2008).

The sampling design from 2006 to 2011 was modified in accordance with recommendations from the 2005 Assessment Framework Workshop on the sGSL snow crab (DFO 2006; Moriyasu et al. 2008). The new design was introduced to achieve spatial sampling homogeneity. While this survey design was spatially unbiased in the sense that the expected number of stations per 10 by 10 minute grid was proportional to its surface area, in practice the realized number of stations per grid was either one or two stations, and grids along the survey area margins often had zero stations. Past survey stations were retained as much as possible, but others were removed or added to grids as prescribed by the sampling method (Hébert et al. 2007; Moriyasu et al. 2008).

In 2012, the sampling design was again modified following recommendations from the 2011 Snow Crab Assessment Methods Framework Science Review (DFO 2012a). The boundaries of the survey area were extended to the 20 and 200 fathom isobaths, encompassing the vast majority of favorable snow crab habitat (i.e. bottom temperatures less than 5°C) and thus the sGSL biological unit. To further improve spatial homogeneity, grids were set to be square rather than rectangular with dimensions defined as a function of the number of total samples, so that each grid included only a single sampling station (DFO 2012a). This protocol resulted in an entirely new set of sampling stations. The revised survey sampling design in 2012 is presented in Wade et al. (2014). For 2013, the number of stations increased from 325 to 355 following recommendations from the snow crab advisory committee to increase the precision of the biomass estimates in smaller fishing zones. The survey area was partitioned into square grids of 12.7 km x 12.7 km and a new set of sampling stations was generated.

3.1.1. Trawl survey in 2014

The redesign of the sampling grid in 2013 and random assignment of stations in each square resulted in an important number of rejected tows due to trawling over rough bottom and gear damage. A total of 444 tows were conducted to realize the 352 successful tows. There is a higher probability of gear damage and failed tows when stations are randomly assigned and sampled, rather than using fixed stations known to be conducive to successful trawling within individual grid squares. Use of fixed stations in subsequent years is a reasonable approach to optimize data collection efforts (DFO 2014). In 2014, the number of sampling stations remained at 355. However, the 352 successful sampling stations from the 2013 trawl survey were used as fixed stations in 2014 and a new set of 3 sampling stations (the 3 sampling stations that were abandoned in 2013) was generated randomly (Fig. 2).

The trawl survey was conducted between July 9 and October 12 and covered Areas 12, 19, 12E and 12F (Fig. 2). The "*Jean-Mathieu*", a 65 foot stern-trawling (720 HP) steel boat, was used to conduct the trawl survey in 2014. A detailed description of the 2014 trawl survey is provided in Moriyasu et al. (2015).

A Bigouden Nephrops bottom trawl net, originally developed for Norway lobster (*Nephrops norvegicus*) fisheries in France, was used (20 m opening with a 28.2 m foot rope). The net is made of 2.5 mm diameter braided nylon twine and the mesh sizes are 80 mm in the wings, 60 mm in the belly and 40 mm in the cod-end (See Moriyasu et al. 2008 for more details on the description of the trawl).

All stations were trawled during the interval between morning and evening civil twilight hours. A predetermined amount of warp was let out (three times the distance of the depth) before the

winch drums were locked. The start time of a standard tow was based on the information reported by the eSonar® depth and height sensors, later revised using data from a Minilog® temperature-depth probe attached to the trawl. The target duration of each tow was 5 minutes at a target speed of 2 knots. The horizontal opening of the trawl was recorded every four seconds with the eSonar® distance sensors. The swept distance of the trawl was estimated from the position (latitude/longitude) measured every second with a DGPS system. The swept area for each tow was calculated by multiplying the swept distance and the horizontal opening of the trawl over the duration of the tow.

Tows were rejected if the net was damaged, the Sonar® system generated no usable data to determine the beginning of the tow, or the duration of the tow was less than four minutes. A replacement tow was conducted near the original start point or at the alternate sampling stations within the assigned grid (Fig. 2).

When the tow satisfied trawl survey protocols but the data signal quality from the eSonar® sensors was deemed to be inadequate to calculate the swept area, the swept area of the tow was set to the average of the values of the 10 nearest stations.

3.1.2. Biological sampling

The trawl catches were sorted on the vessel deck. Snow crabs were put aside for detailed sampling. All other organisms were sorted by species or species group and counted. Starting in 2013, all species or species group were weighed. Since 2010, individual length measurements for each fish species were made at 100 randomly selected stations. Fish length sampling was based on sub-samples of up to 100 individuals of each fish species in a selected tow.

The following information was recorded for all snow crabs: carapace width (CW), chela height (CH) for males and width of the 5th abdominal segment (AW) for females to the nearest 0.1 mm, carapace condition (Hébert et al. 1997), and individual weights of males larger than 95 mm CW. For females, the color (orange, dark orange, brown or black) and quantity (in percentages) of external eggs on ovigerous females, as well as the color (white, beige or orange) of the gonads of immature females were also noted.

The size frequency distributions for the population were derived from the samples weighted by the swept area (km^2) of each corresponding tow.

3.1.3. Estimation of snow crab abundance

The assessment follows the recommendations from the November 2011 Framework Science Peer Review of stock assessment methods for the sGSL snow crab stock (DFO 2012a).

The kriging polygon (and the survey area) has a total area of 57,840 km^2 (Fig. 3) and is partitioned into the four management areas for our analyses: 48,028 km^2 for Area 12, 3,833 km^2 for Area 19, 2,443 km^2 for Area 12E and 2,438 km^2 for Area 12F (Fig. 3). An additional unassigned zone A (above Areas 12E and 12F, Fig. 3) is included in the expanded polygon and located where no fishing activities were observed. This zone has an area of 674 km^2, while the buffer zones B and C (Fig. 3) cover an area of 112 and 310 km^2, respectively.

The sGSL biomass estimates includes the unassigned zone A and the buffer zones B and C (no fishing zones) (Fig. 3). Commercial biomass estimates in each management zone 12, 19, 12E and 12F were calculated excluding the buffer zones.

Commercial biomass estimates were also calculated for each of the buffer zones (B and C) and for the unassigned zone (A).

The current model, kriging with external drift (KED) using depth as a secondary variable, used for the snow crab assessment is considered to be theoretically correct and suitable for biomass estimates (DFO 2012a).

A three-year average for the global variogram was calculated as this has been considered a more stable method for modeling the autocorrelation between the samples (Wade et al. 2014).

The 1997 to 2014 time series of estimated biomasses for the Gulf, using the expanded polygon of 57,840 km^2, was considered as a standardized time series for the purpose of stock assessment, development of reference points and provision for catch advice.

The data were analyzed using an integrated MATLAB toolbox (MPOGEOS), developed at the Ecole Polytechnique de Montréal, which incorporates all the functions required to perform a complete geostatistical analysis (Wade et al. 2014).

Biomass was estimated using KED on commercial-sized adult catch weights (Wade et al. 2014), with the weight estimated using a size-weight relationship:

$$W = (2.665 \times 10^{-4})\ CW^{3.098}$$

where W is the weight in grams and CW is the carapace width in mm (Hébert et al. 1992).

Total biomasses were estimated for the following categories of male crab:

- commercial-sized adult male ≥ 95 mm CW all carapace conditions,
- commercial-sized adult male crab ≥ 95 mm CW with carapace conditions 1 and 2 at the time of the survey, which represents the annual recruitment to the fishery (called R-1), and
- adult male crab ≥ 95 mm CW with carapace conditions 3, 4 and 5 (hard-shelled) at the time of the survey, which represent the residual or remaining biomass post- fishery.

The abundance indices of prerecruits at the time of the survey (R-4, R-3 and R-2) were used to forecast the recruitment to the fishery over the next four years. Stages R-4, R-3 and R-2 represent adolescent males with a CW range of 56-68 mm, 69-83 mm and larger than 83 mm, respectively and they are expected to recruit (CW ≥ 95 mm) to the fishery in 4, 3 and 2 years, respectively. The size increments from molting of pre-recruits R-4, R-3 and R-2 were set using a growth model for adolescent male snow crab (Hebert et al. 2002). The abundance of adolescent males of instar VIII defined as those with a CW between 34 and 44 mm was also estimated as an index of longer term recruitment. It takes at least six years for an adolescent male of instar VIII to reach the commercial size of 95 mm CW. In addition, the abundance indices of pubescent, primiparous and multiparous females were estimated.

3.2. ESTIMATION OF THE ANNUAL MORTALITY (Z) AND EXPLOITATION RATES

Annual mortality rates (*Z*) of commercial-sized adult male crab were calculated from trawl survey abundance estimates:

$$Z = -Ln(N_t^{3,4,5} / N_{t-1}^{1,2,3,4,5})$$

where $N_{t-1}^{1,2,3,4,5}$ is abundance of commercial-sized adult crab with carapace conditions 1 to 5 after the fishery in year *t -1* and $N_t^{3,4,5}$ is the abundance of commercial-sized adult crab with carapace conditions 3, 4 and 5 after the fishery in year *t*. The corresponding proportion of annual loss is given by $1 - exp^{-Z}$.

The exploitation rate (*ER*) was calculated as the ratio of the catch (*t*) in the fishery of year *t* ($C_t^{3,4,5}$) and the commercial biomass (B_{t-1}) from the previous year *t – 1*.

$$ER_t = C_t^{3,4,5} / B_{t-1}^{1,2,3,4,5}$$

This exploitation rate does not consider natural mortality before or during the fishery.

3.3. RISK ANALYSIS AND CATCH OPTIONS

The Bayesian model described by Surette and Wade (2006) and Wade et al. (2014) was used to forecast the biomass of recruitment to the fishery (R-1, commercial-sized adult male crab of carapace conditions 1 and 2) based on survey abundances of pre-recruits R-4, R-3 and R-2 from the sGSL, to project three, two and one year(s) into the future, respectively. The model incorporated uncertainties associated with observation errors.

4.0. RESULTS AND DISCUSSION

4.1. ESTIMATES OF BIOMASS AND EXPLOITATION IN 2014

4.1.1. Southern Gulf

4.1.1.1. Variogram

The three-year averaged variogram model for commercial-sized adult males in 2014 had a nugget value of 1.02×10^6, a sill at 6.988×10^5 and a range of 39.35 km (Fig. 4). The annual variogram model for 2014 had a nugget value of 1.486×10^6, a sill at 6.836×10^5 and a range of 44.04 km (Fig. 5).

4.1.1.2. Biomass estimates

The 2014 kriged commercial biomass estimate was 67,534 t (95% confidence interval (C.I.) range of 60,994 to 74,579 t), an increase of 2.5% from the 2013 estimate of 65,868 t (56,283 – 76,610 t) (Table 1). The recruitment to the fishery at the time of the 2014 survey was estimated at 43,630 t (36,774 – 51,388 t), an increase of 11.9% from the 2013 estimate of 38,981 t (28,969 – 51,346 t) and represents 64.6% of the commercial biomass (Table 1). The 2014 residual biomass (adult commercial-sized males with carapace conditions 3, 4 and 5) was estimated at 23,897 t (20,927 – 27,168 t), a decrease of 11.1% compared to the 2013 estimate of 26,886 t (22,909– 31,352 t) (Table 1).

In 2014, local concentrations of commercial crab were mainly observed in Bradelle Bank, Orphan Bank, Chaleur Bay, in the central and southern parts of the Magdalen channel and in the southeastern part of the sGSL (Fig. 6).

By carapace condition in 2014, commercial crabs were comprised of 63.2% fishery recruitment (carapace conditions 1 and 2) and 36.8% residual biomass (carapace conditions 3, 4 and 5) (Table 2). Further split by carapace condition, the residual biomass is composed of 25.7% of commercial crab with carapace condition 3, 11.4% of crabs with carapace condition 4 and 0.6% of crabs with carapace condition 5 (Table 2). This suggests that the composition of the commercial male population observed in the 2014 trawl survey is young and there is no sign of an ageing population at this moment. Close monitoring of catch composition from the at-sea observer sampling and survey data is necessary to monitor the ageing of the commercial male population in the coming years.

A comparison between fishery recruitment predicted from the Bayesian model for 2015 (37,893 t; C.I. 28,568 – 49,114 t), which was based on the abundance of prerecruits from the

2013 trawl survey, and the recruitment biomass from the 2014 survey (43,630 t; 36,774 - 51,388 t) indicated that the estimated recruitment for the 2014 fishery is well within the 95% credibility interval of the predicted value (Table 3; Fig. 7). The relationship between the abundance of R-2 prerecruits in year *t* and the recruitment to the fishery in year *t + 1* is shown in Figure 8. A number of factors can account for the variability in this relationship, including variations in bycatch mortality, natural mortality, the molting schedule of precreruits (skip molting, molting to adolescent phase or molting to adult phase), and sampling error.

4.1.2. Estimation of the portion of total biomass in each management fishing zone and buffer zone

4.1.2.1. Area 12

The 2014 trawl survey estimate of commercial biomass for Area 12 was 59,858 t (54,125 - 66,029 t) (Table 4). This estimate corresponds to 89.2% of the sum of the independently estimated commercial biomasses in the four management zones.

4.1.2.2. Area 19

The 2014 post-fishery trawl survey estimate of the commercial biomass was 5,524 t (4,332 – 6,943 t) (Table 4). This estimate corresponds to 8.2% of the sum of the independently estimated commercial biomasses in the four management zones.

4.1.2.3. Areas 12E and 12F

Areas 12E and 12F lie at the margins of snow crab habitat in the sGSL and contain few sampling stations and have correspondingly uncertain biomass estimates with very large confidence intervals.

The Area 12E commercial biomass from the 2014 trawl survey was estimated at 487 t (67 – 1,765 t), (Table 4). This estimate corresponds to 0.7% of the sum of the independently estimated commercial biomasses in the four management zones.

In Area 12F, the commercial biomass from the 2014 trawl survey was estimated at 1,210 t (486 – 2,523 t), (Table 4). This estimate corresponds to 1.8% of the sum of the independently estimated commercial biomasses in the four management zones.

4.1.2.4. Buffer zones and unassigned zone

Commercial biomass estimates in the buffer zones and in the unassigned zone have very large confidence intervals given the low number of stations within these small zones.

The commercial biomass in the unassigned zone A above Areas 12E and 12F (Fig. 3) was 43 t (0 – 293 t) (Table 4). The commercial biomass in buffer zone B (2 nautical mile wide buffer zone) adjacent to Area 19 and 12F (Fig. 3) was estimated at 89 t (36 - 185 t) (Table 4). The commercial biomass in buffer zone C (5-miles buffer zone) located south of Area 19 (Fig. 3) was 315 t (146 - 597 t) (Table 4).

The sum of the commercial biomass estimates in the management, buffer, and unassigned zones in 2014 was 67,526 t, very close to the sGSL biomass estimate, 67,534 t (Table 4).

4.1.3. Exploitation rate

The exploitation rate in 2014 was 37.1% (Table 5; Fig. 9). The exploitation rates have varied between 20.8% and 45% from 1998 to 2013 (Table 5; Fig. 9).

4.1.4. Annual mortality (Z) and difference in commercial-sized adult males

The annual mortality rate (Z), expressed as a proportion of commercial-sized adult male snow crab in the sGSL was estimated at 63.7% in 2014 and has varied between 45.8% and 82.5% since 1997 except for 2011 where it was estimated at 5.6% (Fig. 9).

Over the time series, the sum of commercial biomasses from the survey was 29.4% higher than the sum of the residual biomasses and landings of the following year (Fig. 10). This difference (termed non-fishing directed mortality) could be attributed to a number of factors including misattribution of recruitment and residual groups, variability in survey estimates, natural mortality, non-directed fishery induced mortalities, as well as crab movement in and out of the sampling area.

4.1.5. Reproductive potential

The abundance of adult males increased from 1997 to 1999, remained stable until 2004 and gradually decreased until 2009 (Fig. 11). From 2009 to 2012, the abundance of adult males increased to levels comparable to those observed during the 1999-2004 period (Fig. 11). The abundance of adult males decreased in 2013 but increased in 2014 to levels comparable to the 2009-2012 period (Fig. 11). The abundance of mature females in 2014 remained high relative to the low values observed during 2006 to 2009 (Fig. 12). Over the time series, the annual mean size of mature females varied from 57.4 mm in 1999 to 61.7 mm CW in 2005 (Fig. 13). The mean size of mature females was 57.5 mm CW in 2014 (Fig. 13).

5.0. RISK ANALYSIS OF CATCH OPTIONS AND PROGNOSIS

Within the Precautionary Approach framework (DFO 2009), the limit reference point for biomass (B_{lim}) defines the critical / cautious zones and an upper stock reference point (B_{USR}) delimits the cautious / healthy zones on the stock status axis. A removal rate limit reference point (F_{lim}) defines the maximum removal rate in the healthy zone. Reference points which conform to the Precautionary Approach were developed in 2010 for the snow crab biological unit of the sGSL (DFO 2010b). The change in methodology derived from the 2011 Snow Crab Assessment Methods Framework Science Review required the recalculation of the time series of biomass estimates and the Precautionary Approach reference points (DFO 2012b).

The rescaled B_{USR} is set at 41,400 t of commercial-sized adult males of all carapace conditions, which is 80% of the biomass of maximum sustainable yield (B_{MSY}) with the proxy for B_{MSY} chosen as 50% of the maximum estimated commercial biomass for the 1997 to 2008 time period (Table 5; Fig. 14). The rescaled B_{lim} value is 10,000 t (Table 5; Fig. 14). The B_{lim} was chosen as the lowest biomass of hard shelled commercial-sized adult males, which was observed in 2000 (residual biomass estimated from the trawl survey) (DFO 2010b). The rescaled F_{lim} has been set at 34.6% (Table 5; Fig. 14), which is the average annual exploitation rate calculated as catch (weight) in year *t+1* divided by the estimated biomass of commercial-sized adult male crab from the post-fishery trawl survey in year *t* for the 1997 to 2009 time period (DFO 2010b).

5.1. RISK ANALYSIS OF CATCH OPTIONS FOR 2015

The estimated commercial biomass available for the 2015 fishery in the sGSL is 67,534 t (60,994 to 74,579 t), which is in the healthy zone of the precautionary approach framework (Fig. 14).

The predicted recruitment of commercial crab for the 2016 fishery based on the Bayesian pre-recruit model (Surette and Wade, 2006; Wade et al., 2014), using the 2014 survey data, is 42,300 t (32,760 to 51,840 t), (Table 3; Fig. 15).

Harvest decision rules that conform to the PA have been developed (DFO 2014b). These PA compliant harvest decision rules include rules for which the exploitation rate exceeds F_{lim} when the stock is in the healthy zone (DFO 2014b). The Snow Crab Advisory Committee agreed on the proportional harvest decision rule (variant 4 in DFO 2014b, Figure 16) to derive the exploitation rate and the TAC based on the estimated biomass from the southern Gulf of St. Lawrence snow crab survey. This decision rule and the corresponding estimated commercial biomass from the 2014 survey of 67,534 t, results in a selected exploitation rate of 38.55% and corresponding to a TAC of 26,036 t for the 2015 fishery (Fig. 16).

A risk analysis was developed for the decision rule TAC and relative to other catch levels in 2015 (Table 6, Fig. 17). The risk analysis indicates that the TAC derived from the harvest decision rule will result in a near zero chance of the residual biomass after the fishery being less than B_{lim} and a near 100% chance of the biomass for the next year's fishery being above B_{USR} and in the healthy zone of the PA (Table 6, Fig. 17). The risk analysis also provides predictions of the commercial biomass in the 2015 survey, assuming the corresponding catch level is taken in 2015. At the decision rule TAC value of 26,036 t for the 2015 fishery, the commercial biomass predicted for the 2015 post-fishery survey and for the 2016 fishery, is 65,680 t, with a 95% confidence interval range of 54,800 to 76,410 t (Table 6), a value similar to the 2014 survey. The commercial biomass projections for 2016 according to different catch options for the 2015 fishery are presented in Table 6.

A number of factors can account for the variation in the recruitment rate of the pre-recruits to the commercial-sized adult stage including unaccounted bycatch mortality, sampling uncertainties, natural mortality and variations in the molting schedule of pre-creruits (skip molting, molting to adolescent phase or molting to adult phase) especially if density-dependent phenomena occur. In addition, in these two-year commercial biomass projections, we used a forecast survivorship rate of 0.73, which is a 5-year moving average. In the past, the survivorship rate has varied considerably from one year to the next which affect directly the commercial biomass projections.

5.2. PROGNOSIS

The fishery recruitment and the commercial biomass (by taking into account the application of the decision rule of 38.55% exploitation rate for the 2015 fishery) are expected to be 42,300 t (32,760 t to 51,840 t) and 65,680 t (54,800 t to 76,410 t), respectively for the 2016 fishery (Tables 3 and 6). A small pulse of adolescent males, between 15 and 32 mm carapace width was observed in the 2014 survey (Fig. 18). The abundance of males with a CW between 34 and 44 mm, which will reach the commercial size in 6 years, decreased in 2014 (Fig. 19). The abundance of prerecruits ≥ 56 mm CW (R-4, R-3, R-2) increased in 2014 compared to 2013 (Table 3). The area occupied by these crabs in the 2014 survey was mostly in Shediac Valley and in the southern part of the sGSL (Fig. 20).

The estimated abundances of immature and pubescent females in the population increased from 2001 to 2012 but decreased in 2013 and 2014 (Figs. 12 and 21). The decrease in pubescent females observed in the 2014 trawl survey suggests that the abundance of mature females may decrease in the coming years. The abundance of mature females remained high in 2014 relative to the low values observed during 2006 to 2009 (Figs. 12 and 21).

6.0. UNCERTAINTIES

6.1. CHANGE IN THE SURVEY PROTOCOL AND VARIABILITY IN THE COMPOSITION OF COMMERCIAL BIOMASS

A number of survey protocol changes have weakened the assumption of homogeneity of the biomass time series.

Four different boats have been used to conduct the trawl survey: the "Emy-Serge" (1988-1998), a 65-foot side-trawling (375 HP) wooden boat, the "Den C. Martin" (1999-2002), a 65-foot stern-trawling (402 HP) steel boat, the "Marco-Michel" (2003-2012), a 65 feet stern-trawling (660 HP) fiberglass boat and the "Jean-Mathieu" in 2013, a 65-foot stern trawling (720 HP). Individual tows were standardized by trawl swept area using data from trawl acoustic monitoring sensors (Moriyasu et al. 2008). However other factors may contribute to varying catchability among boats, but no comparative fishing studies were performed. A preliminary statistical comparison between snow crab survey and September multispecies survey data suggests that the boats did have different catchabilities, which can alter our perception of stock dynamics (Benoît and Cadigan 2013). Work is ongoing to refine the estimates of relative catchabilty of the vessels.

The kriging polygon or the area over which the abundance or biomass is estimated has increased over the years. The discrepancy between the survey area, i.e. that over which trawl samples are extracted, and the latest kriging polygon is more pronounced farther back in time. Thus there is more extrapolation and potential for bias for these earlier years.

A Snow Crab Assessment Methods Framework Science Review conducted in November 2011 addressed these concerns as well as changes in survey design. Following the review, it was agreed that the time series from 1997 to the present was sufficiently coherent to be used in assessing stock status and providing catch advice (DFO 2012a). Further work is required to determine if the earlier part of the time series between 1989 and 1996, for which survey coverage was much less than the coverage from 1997 to the present, could also be used for assessment purposes.

6.2. GROWTH

Recruitment to the fishery for snow crab is highly variable from year to year (Comeau and Conan 1992; Sainte-Marie et al. 1995; Comeau et al. 1998a; Moriyasu et al. 1998) depending on environmental conditions, predation and population levels. In sGSL snow crab stocks, the biomass of commercial-sized adult male crab appears to fluctuate from periods of 3 to 4 years of high recruitment followed by 3 to 4 years of low recruitment (Sainte-Marie et al. 1995; Comeau et al. 1998a; Moriyasu et al. 1998). Since molting activity peaks in January for adolescent skip-molters and in March for normal molters, most postmolt males are potentially catchable as soon as the fishery starts (generally at the end of April). Soft-shelled males in the commercial catches are found from late April to August in the sGSL (Hébert et al. 2002).

The mechanism of molting to terminal phase is complex. Conan et al. (1988), and Comeau et al. (1998a) hypothesized that the molt to terminal phase for a given size group may be density-dependent rather than genetically determined. Waiwood and Elner (1982) hypothesized that the removal of large old crab would release the snow crab population from a "stagnant" to a "dynamic" high-growth phase. Comeau et al. (1998a) suggested that a high abundance of large mature (adult) males in the population may trigger molting to another larger juvenile (adolescent) instar stage instead of molting to the terminal phase. Alternatively growth could be inhibited resulting in an increased abundance of skip molters. The annual trawl survey since 1988 showed a very high (up to 50–60% in peak years) skip molting rate in adolescent males larger than 50 mm CW. Such a high percentage of skip molters may reflect a density-dependent

effect on the molting schedule of larger adolescent males. This may be a driving factor affecting the strength and timing of recruitment to the fishery.

6.3. ENVIRONMENTAL CONSIDERATIONS

Environmental factors, such as water temperature, can affect molting, reproductive dynamics and the movement of snow crab. Chassé and Pettipas (2009) reported that bottom temperatures over most of the southern Gulf of St. Lawrence are typically between -1 and 3ºC, a temperature range suitable for snow crab habitat. Data collected during research surveys indicate that the bottom temperatures in deeper waters of Areas 12E and 12F are higher (1 to 5ºC) than on the crab grounds (-1 to 2ºC) in Area 12. Bottom temperatures in Area 19 are usually 1 to 2 ºC warmer than on the traditional crab grounds in Area 12 (Chassé and Pettipas 2009).

In 2014, near-bottom temperatures were at the mean value for the period 1981 to 2010 in most of the central portion of Area 12, as well as in Areas 12E and 12F, and above average on the western portion of the southern Gulf of St. Lawrence (i.e. Shediac Valley area). The bottom waters around Magdalen Island and St. Georges Bay were cooler than average. Temperatures in Area 19 were around the average value except along its northwest limit where they were slightly lower than average. The average September bottom temperature, over the whole southern Gulf, was near the long-term average value. Most of the snow crab fishing grounds cooled down in 2014 compared to 2013, except for the Shediac Valley area where the water was significantly warmer. The snow crab habitat index (bottom area with temperatures from -1 to 3°C) was just 1.2% below average in 2014 and similar to 2013. The mean temperature (0.6°C) within the defined snow crab habitat area index (-1 to 3°C) in 2014 decreased by about 0.4°C compared to 2013 (1.0ºC). In 2012, the mean temperature was the highest of the 44 year time series and the 2013 temperature remained significantly higher than the long-term mean, but the 2014 value is now below the long-term average, directly associated with the cold winter meteorological conditions of 2014. The mean temperature had been above average over the five previous years and for 12 of the last 16 years.

Snow crab is a stenothermic species with a preference for colder water temperatures. A temperature regime shift from cold to warm may have impacts on population dynamics of snow crab such as shortened reproductive cycles, increased per capita fecundity, and increased size at maturity, greater natural mortality, spatial contraction of habitat, and skewed sex ratio for reproduction. The stock may be more vulnerable to commercial fishing pressure under climate-driven changes resulting in increasing temperatures. Furthermore, the outcome of climate change on snow crab population dynamics can be relatively abrupt and even detrimental, and the direction of the effect may be difficult to predict (Sainte-Marie et al. 2008).

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TABLES

Table 1. Estimated biomass (t, mean and 95% confidence interval in parentheses) of commercial-sized adult male snow crab, Chionoecetes opilio, in the southern Gulf of St. Lawrence (all zones) by kriging in weight, 1997 to 2014. Recruitment refers to snow crab with carapace conditions 1 and 2 whereas residual biomass refers to snow crab with carapace conditions 3 to 5.

Survey year	Commercial biomass	Recruitment biomass	Residual biomass
1997	65,310 (54,801-77,239)	37,619 (26,376-52,064)	27,690 (21,995-34,407)
1998	57,595 (45,630-71,735)	29,818 (17,580-47,435)	27,775 (21,022-36,013)
1999	57,051 (47,946-67,376)	25,874 (15,918-39,818)	31,177 (25,051-38,346)
2000	49,823 (40,473-60,682)	39,845 (30,543-51,093)	9,977 (6,649-14,401)
2001	59,150 (47,740-72,460)	42,243 (31,198-55,942)	16,905 (12,657-22,125)
2002	79,559 (66,688-94,181)	66,481 (53,434-81,746)	13,075 (10,451-16,157)
2003	84,423 (71,964-98,410)	57,503 (44,809-72,679)	26,919 (21,223-33,674)
2004	103,429 (91,029-117,036)	83,702 (70,955-98,069)	19,726 (15,836-24,280)
2005	82,537 (73,487-92,387)	58,398 (48,417-69,824)	24,140 (18,726-30,632)
2006	74,285 (66,192-83,087)	54,371 (46,124-63,660)	19,914 (16,161-24,275)
2007	66,660 (60,183-73,638)	39,635 (33,089-47,092)	27,025 (23,354-31,106)
2008	52,564 (46,658-59,006)	31,555 (25,181-39,048)	21,010 (17,960-24,426)
2009	30,920 (27,237-34,959)	20,520 (16,848-24,754)	10,399 (8,560-12,516)
2010	35,795 (31,681-40,291)	20,351 (15,360-26,450)	15,444 (12,859-18,394)
2011	63,162 (55,965-71,022)	29,394 (20,909-40,190)	33,768 (28,297-39,985)
2012	74,997 (65,822-85,086)	48,969 (38,667-61,173)	26,028 (21,950-30,641)
2013	65,868 (56,283-76,610)	38,981 (28,969-51,346)	26,886 (22,909-31,352)
2014	67,534 (60,994-74,579)	43,630 (36,774-51,388)	23,897 (20,927-27,168)

Table 2. Abundance (number by 10^6; mean and 95% confidence interval) of commercial-sized adult male crabs by carapace condition (CC 1+2, CC3, CC4 and CC5) in the southern Gulf of St. Lawrence, 1997 to 2014.

Survey year	Carapace condition 1+2			Carapace condition 3			Carapace condition 4			Carapace condition 5		
	Mean	Confidence interval		Mean	Confidence interval		Mean	Confidence interval		Mean	Confidence interval	
1997	61.272	51.848	71.906	27.858	22.644	33.910	17.144	13.556	21.391	5.675	4.154	7.574
1998	51.738	41.550	63.665	23.956	18.874	29.986	15.711	12.041	20.150	8.891	6.220	12.327
1999	49.755	40.294	60.766	32.840	25.189	42.086	16.258	12.637	20.594	7.874	5.239	11.380
2000	67.530	51.847	86.473	10.242	5.622	17.199	7.384	4.455	11.538	2.527	1.147	4.860
2001	76.238	60.652	94.604	26.667	21.371	32.876	5.134	2.502	9.401	1.474	0.393	3.917
2002	112.785	95.089	132.807	21.605	17.356	26.578	4.318	2.646	6.664	0.893	0.411	1.701
2003	99.346	84.820	115.635	38.180	30.183	47.646	11.431	7.097	17.466	1.715	0.717	3.485
2004	138.152	120.945	157.106	28.964	23.320	35.559	9.867	7.684	12.479	1.072	0.671	1.629
2005	97.311	87.537	107.870	30.516	23.465	39.022	10.679	8.049	13.895	0.567	0.217	1.222
2006	84.216	75.183	94.027	29.830	24.513	35.955	5.725	3.991	7.961	1.030	0.552	1.762
2007	62.530	55.515	70.179	32.053	25.962	39.141	14.243	10.714	18.566	1.004	0.523	1.752
2008	51.110	44.873	57.967	23.028	18.600	28.191	11.440	8.614	14.900	3.081	1.951	4.635
2009	31.729	27.218	36.771	12.714	10.170	15.701	5.393	3.832	7.379	1.276	0.685	2.179
2010	32.854	28.548	37.624	20.628	16.819	25.040	4.223	3.236	5.417	1.567	0.925	2.490
2011	53.387	46.199	61.369	45.065	37.545	53.646	9.979	7.706	12.713	1.778	1.024	2.878
2012	86.900	72.956	102.723	38.900	32.850	45.736	5.570	4.238	7.676	1.150	0.601	2.002
2013	62.875	54.251	72.471	30.204	25.895	35.020	18.560	14.744	23.060	0.695	0.338	1.273
2014	73.141	63.594	82.687	29.788	25.261	34.315	13.134	10.268	16.000	0.658	0.180	1.136

Table 3. Data used in the risk analysis of catch options: point estimates of abundance (number x 10^6) of snow crab male prerecruits (R-4, R-3 and R-2), the estimated and forecast (from the Bayesian model) values for recruitment biomass (t; R-1), estimated residual biomass (t) and estimated commercial biomass (t) in the southern Gulf of St. Lawrence based on trawl survey data, and survivorship rates (S) between years used for the forecast model of commercial biomass. S is calculated based on a 5-year moving average.

Survey Year	Prerecruits (number X 10^6)			Recruitment to the fishery (t)	Forecast recruitment (t)	Residual biomass (t)	Commercial biomass (t)	Survivorship rates
	R – 4	R - 3	R - 2	R - 1	R-1	Res	B	S
1997	114.2	92.7	57.9	37,619 (26,376-52,064)	na	27,690 (21,995-34,407)	65,310 (54,801-77,239)	na
1998	139.5	91.6	57.1	29,818 (17,580-47,435)	na	27,775 (21,022-36,013)	57,595 (45,630-71,735)	na
1999	199.7	150.9	115.0	25,874 (15,918-39,818)	na	31,177 (25,051-38,346)	57,051 (47,946-67,376)	na
2000	238.7	159.4	89.3	39,845 (30,543-51,093)	na	9,977 (6,649-14,401)	49,823 (40,473-60,682)	na
2001	313.2	229.2	135.7	42,243 (31,198-55,942)	na	16,905 (12,657-22,125)	59,150 (47,740-72,460)	na
2002	166.7	241.8	199.7	66,481 (53,434-81,746)	na	13,075 (10,451-16,157)	79,559 (66,688-94,181)	na
2003	137.8	207.1	181.4	57,503 (44,809-72,679)	na	26,919 (21,223-33,674)	84,423 (71,964-98,410)	na
2004	86.4	122.8	142.5	83,702 (70,955-98,069)	na	19,726 (15,836-24,280)	103,429 (91,029-117,036)	na
2005	63.3	79.4	117.1	58,398 (48,417-69,824)	60,500 (38,800-86,000)	24,140 (18,726-30,632)	82,537 (73,487-92,387)	na
2006	55.0	49.8	65.3	54,371 (46,124-63,660)	49,700 (33,200-73,000)	19,914 (16,161-24,275)	74,285 (66,192-83,087)	na
2007	57.2	47.9	56.0	39,635 (33,089-47,092)	35,200 (21,300-55,000)	27,025 (23,354-31,106)	66,660 (60,183-73,638)	na
2008	80.4	54.3	45.8	31,555 (25,181-39,048)	29,000 (18,500-42,000)	21,010 (17,960-24,426)	52,564 (46,658-59,006)	na
2009	89.4	69.5	43.6	20,520 (16,848-24,754)	27,700 (17,800-38,000)	10,399 (8,560-12,516)	30,920 (27,237-34,959)	na
2010	140.4	109.1	71.8	20,351 (15,360-26,450)	25,900 (17,100-37,000)	15,444 (12,859-18,394)	35,795 (31,681-40,291)	0.65
2011	91.5	98.7	87.6	29,394 (20,909-40,190)	33,700 (22,900-47,000)	33,768 (28,297-39,985)	63,162 (55,965-71,022)	0.69

Survey Year	Prerecruits (number X 10^6)			Recruitment to the fishery (t)	Forecast recruitment (t)	Residual biomass (t)	Commercial biomass (t)	Survivorship rates
	R – 4	R - 3	R - 2	R - 1	R-1	Res	B	S
2012	96.0	86.8	80.4	48,969 (38,667-61,173)	40,700 (31,300-52,400)	26,028 (21,950-30,641)	74,997 (65,822-85,086)	0.69
2013	103.8	87.5	78.4	38,981 (28,969-51,346)	40,380 (31,670-50,380)	26,886 (22,909-31,352)	65,868 (56,283-76,610)	0.73
2014	107.1	96.1	118.5	43,630 (36,774-51,388)	37,893 (28,568-49,114)	23,897 (20,927-27,168)	67,534 (60,994-74,579)	0.72
2015	na	na	na	na	42,300 (32,760-51,840)	na	na	0.73

Table 4. Estimated snow crab commercial biomass (t, mean and 95% confidence interval) in 2014 using kriging with external drift for the southern Gulf overall, by management areas 12, 19, 12E and 12F, and in buffer zones.

Areas	Surface area (km^2)	Commercial biomass (t)	
		Mean	95% confidence interval
Southern Gulf	57,840	67,534	60,994-74,579
Area 12	48,028	59,858	54,125-66,029
Area 19	3,833	5,524	4,332-6,943
Area 12E	2,443	487	67-1,765
Area 12F	2,438	1,210	486-2,523
Sum of management areas	56,742	67,079	na
Unassigned zone above 12E **(A)**	674	43	0-293
Buffer zone 19/12F **(B)**	112	89	36-185
Buffer zone 12/ 19 **(C)**	310	315	146-597
Sum of total areas	57,838	67,526	na

Table 5. Data (from the trawl survey data, 1997 to 2008, using kriging in weights) used in the development of reference points for the snow crab fishery of the southern Gulf and exploitation rates for the fisheries in 1998 to 2014.

Year of the fishery	Landings (t)	Estimated commercial biomass (t) from survey in year-1	Estimated residual biomass (t) from survey in year-1	Exploitation rate (%) (landings fishery year t / commercial biomass fishery year t-1)
		65,310 (54,801-77,239)	27,690 (21,995-34,407)	20.8
1999	15,110	57,595 (45,630-71,735)	27,775 (21,022-36,013)	26.2
2000	18,712	57,051 (47,946-67,376)	31,177 (25,051-38,346)	32.8
2001	18,262	49,823 (40,473-60,682)	9,977 (6,649-14,401)	36.7
2002	25,691	59,150 (47,740-72,460)	16,905 (12,657-22,125)	43.4
2003	21,163	79,559 (66,688-94,181)	13,075 (10,451-16,157)	26.6
2004	31,675	84,423 (71,964-98,410)	26,919 (21,223-33,674)	37.5
2005	36,118	103,429 (91,029-117,036)	19,726 (15,836-24,280)	34.9
2006	29,121	82,537 (73,487-92,387)	24,140 (18,726-30,632)	35.3
2007	26,867	74,285 (66,192-83,087)	19,914 (16,161-24,275)	36.2
2008	24,458	66,660 (60,183-73,638)	27,025 (23,354-31,106)	36.7
2009	23,642	52,564 (46,658-59,006)	21,010 (17,960-24,426)	45.0
2010	9,549	30,920 (27,237-34,959)	10,399 (8,560-12,516)	30.9
2011	10,708	35,795 (31,681-40,291)	15,444 (12,859-18,394)	29.9
2012	21,956	63,162 (55,965-71,022)	33,768 (28,297-39,985)	34.8
2013	26,049	74,997 (65,822-85,086)	26,028 (21,950-30,641)	34.7
2014	24,479	65,868 (56,283-76,610)	26,886 (22,909-31,352)	37.1
2015	na	67,534 (60,994-74,579)	23,897 (20,927-27,168)	na

Table 6. Risk analyses for different catch options in 2015 for the southern Gulf of St. Lawrence snow crab fishery showing probabilities of exceeding the fishing removal rate limit reference point (F_{lim}), of the hard-shelled commercial-sized male biomass falling below the limit reference point for biomass (B_{lim}), and of the total commercial-sized adult male biomass being over the upper stock reference point (B_{USR}) post-fishery in 2015. In bold is the catch option (exploitation rate of 38.55% corresponding to the commercial biomass of 67,354 t) according to the agreed decision rule on the Precautionary Approach (variant 4, DFO 2014b).

	Probability			
Catch option (t) for 2015	> F_{lim} (34.6%)	< B_{lim} (10,000 t)	≥ B_{USR} (41,400 t)	Predicted commercial biomass for 2016 (t)
20,000	0	0	1	71,720 (60,840-82,450)
20,500	0.01	0	1	71,220 (60,340-81,950)
21,000	0.02	0	1	70,720 (59,840-81,450)
21,500	0.06	0	1	70,220 (59,340-80,950)
22,000	0.13	0	1	69,720 (58,840-80,450)
22,500	0.24	0	1	69,220 (58,340-79,950)
23,000	0.38	0	1	68,720 (57,840-79,450)
23,370	0.50	0	1	68,350 (57,080-79,200)
23,500	0.54	0	1	68,220 (57,340-78,950)
24,000	0.70	0	1	67,720 (56,840-78,450)
24,500	0.83	0	1	67,220 (56,340-77,950)
25,000	0.91	0	1	66,720 (55,840-77,450)
26,000	0.99	0	1	65,720 (54,840-76,450)
26,036	**0.99**	**0**	**1**	**65,680 (54,800-76,410)**
27,000	1	0	1	64,720 (53,840-75,450)
28,000	1	0	1	63,720 (52,840-74,450)
29,000	1	0	1	62,720 (51,840-73,450)
30,000	1	0	1	61,720 (50,840-72,450)
39,330	1	0.5	0.95	52,390 (41,510-63,120)
50,210	1	1	0.5	41,510 (30,630-52,240)

FIGURES

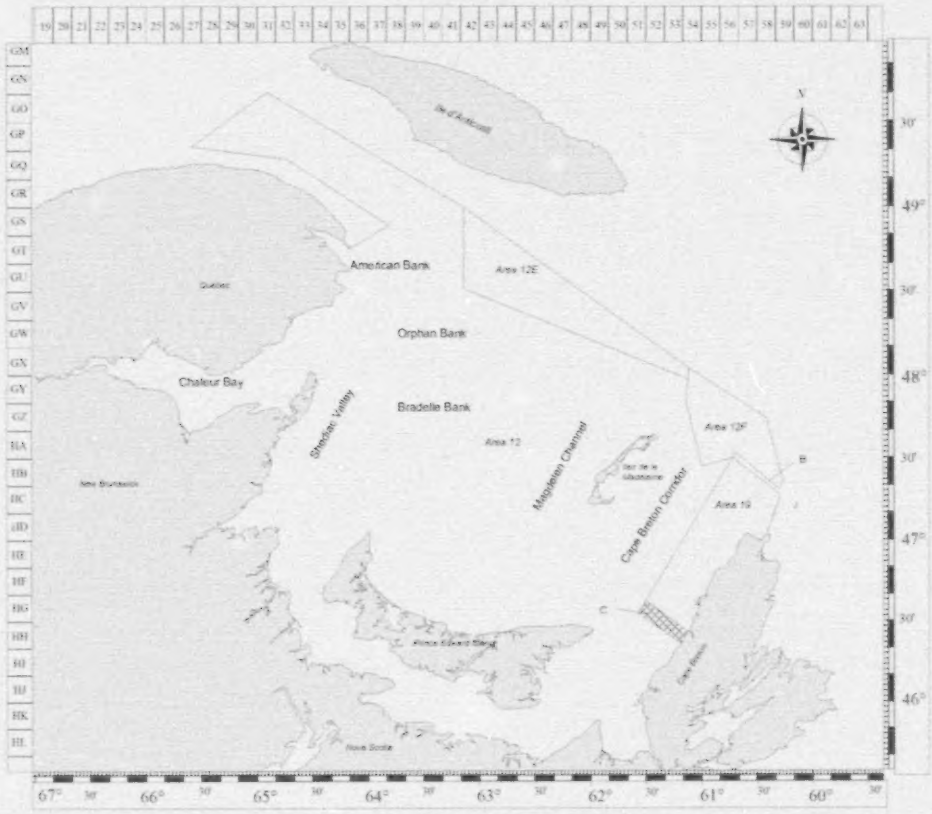

Figure 1. Map of the southern Gulf of St. Lawrence showing the snow crab (Chionoecetes opilio) fishing areas, fishing grounds, and management buffer zones (labels B and C, shaded areas).

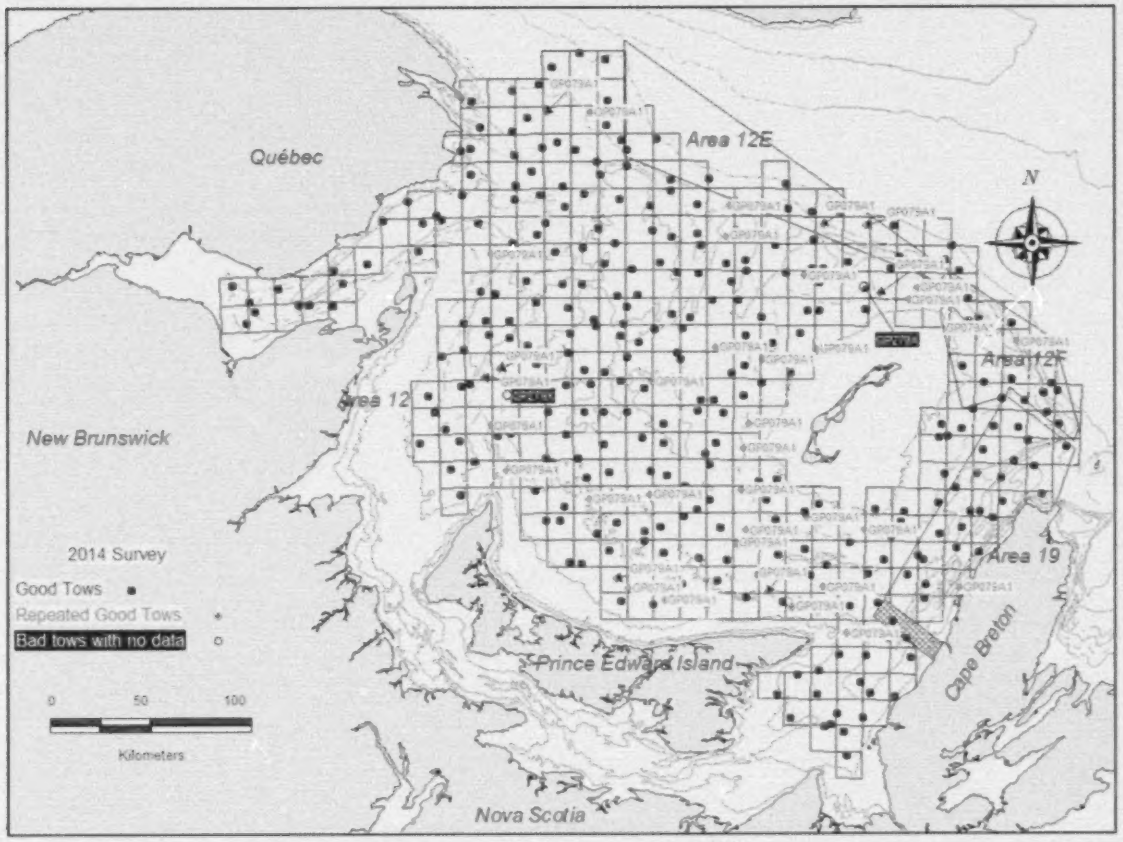

Figure 2. Locations of the 2014 snow crab (Chionoecetes opilio) trawl survey stations within the estimation polygon of 57,840 km^2 in the southern Gulf of St. Lawrence. The blue points are successful tows, red points are successful repeat tows and the yellow points (n = 2) are abandoned grids.

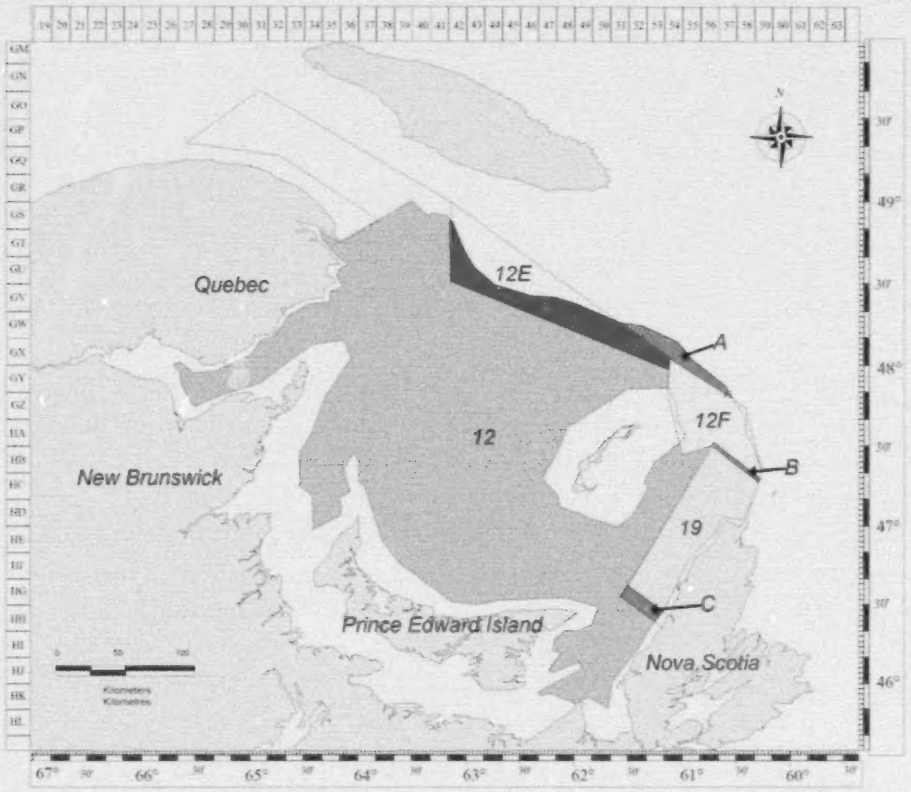

Figure 3. The estimation polygon of 57,840 km^2 used for the 2014 snow crab (Chionoecetes opilio) stock assessment in the southern Gulf of St. Lawrence (all coloured areas) and corresponding estimation polygons for the four crab fishing areas (12, 12E, 12F and 19). The unsigned zone north of areas 12E and 12F (label A) and buffer zones (labels B and C) are also shown.

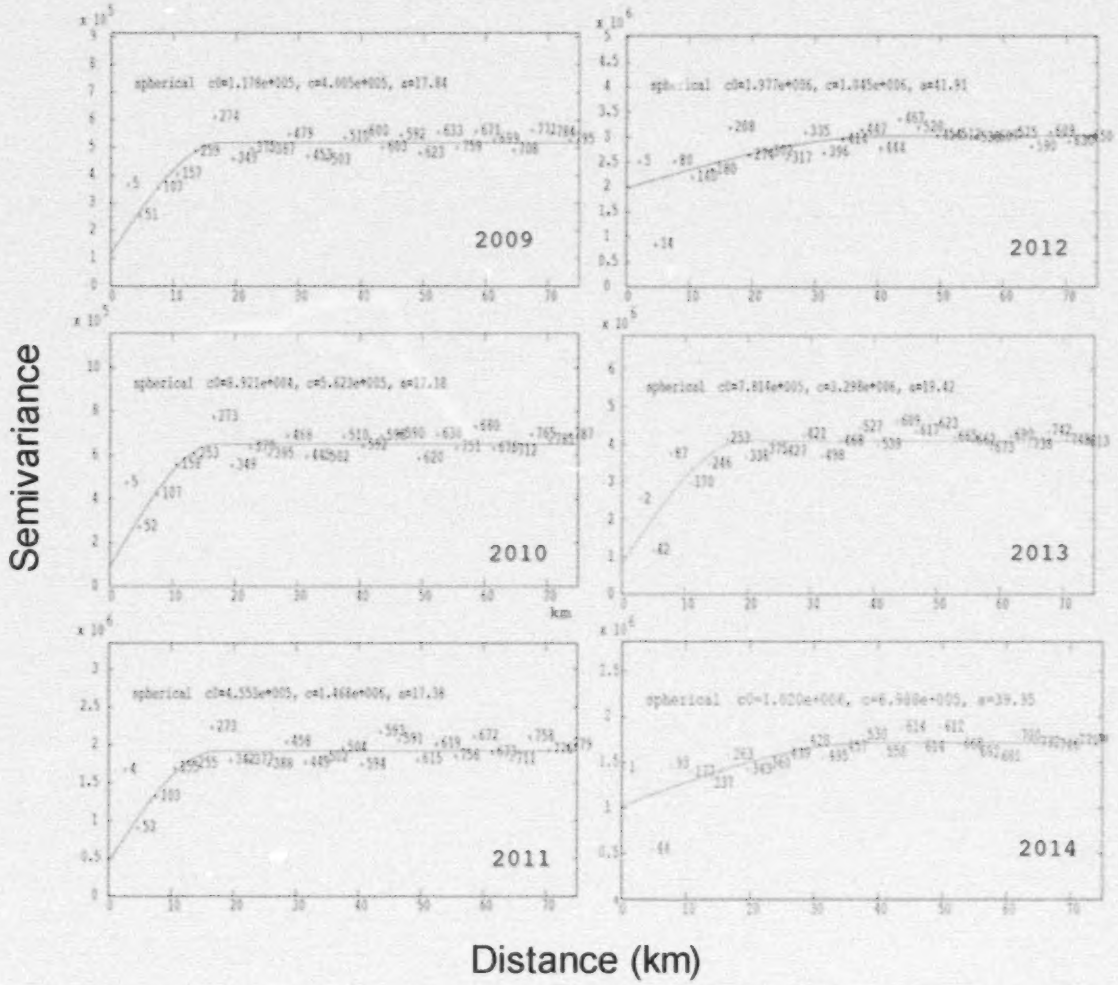

Figure 4. Three-year moving average variogram models for commercial-sized adult male snow crab (Chionoecetes opilio) in the southern Gulf of St. Lawrence, 2009 to 2014. Indicated is the number of paired observations used per distance lag semi-variance calculation.

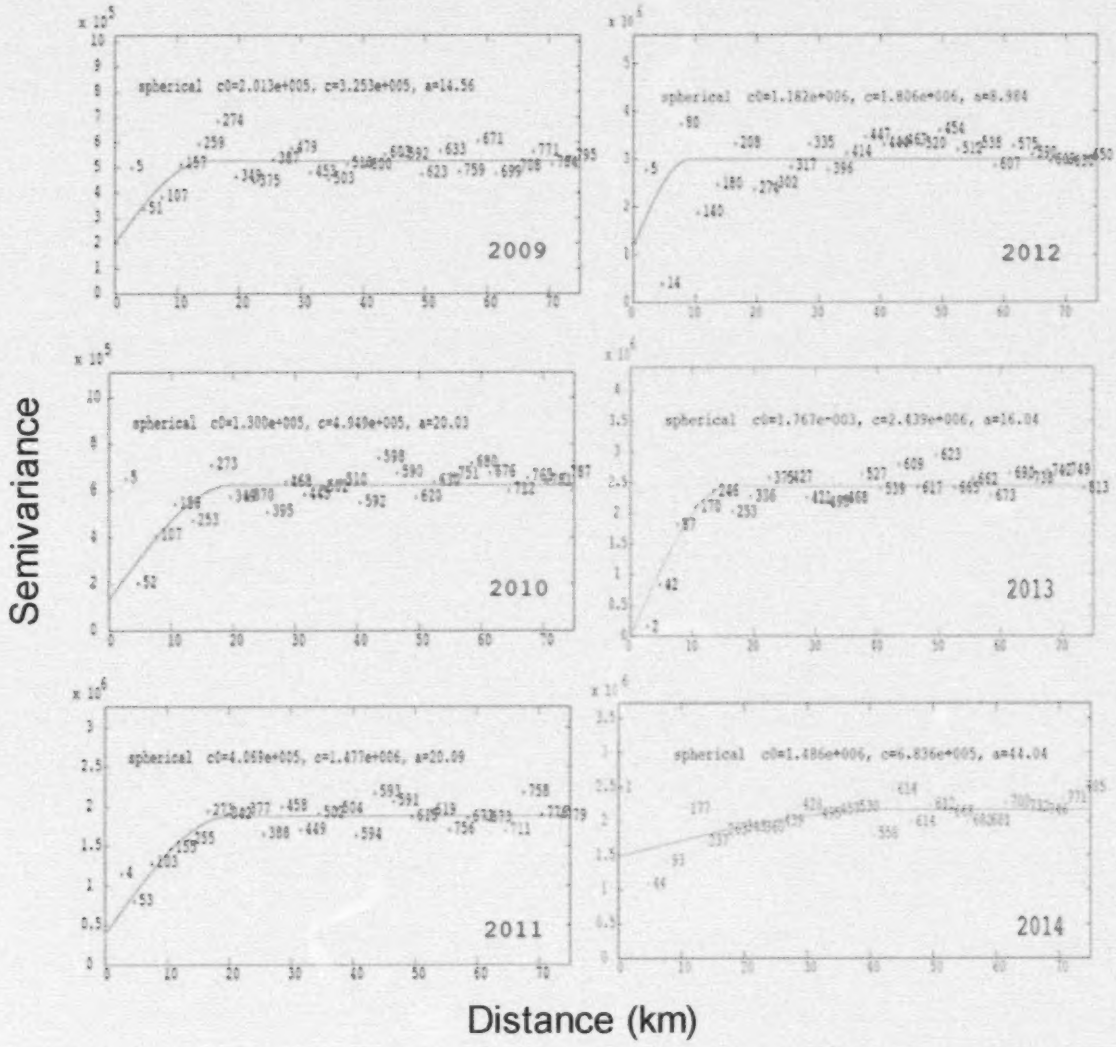

Figure 5. Annual variogram models for commercial-sized adult male snow crab (Chionoecetes opilio) in the southern Gulf of St. Lawrence, 2009 to 2014. Indicated is the number of paired observations used per distance lag semi-variance calculation.

Figure 6. Density (kg per km²) contours of commercial-sized (≥ 95 mm of carapace width) adult male snow crab (Chionoecetes opilio) based on trawl survey data in the southern Gulf of St. Lawrence, 2003 to 2014.

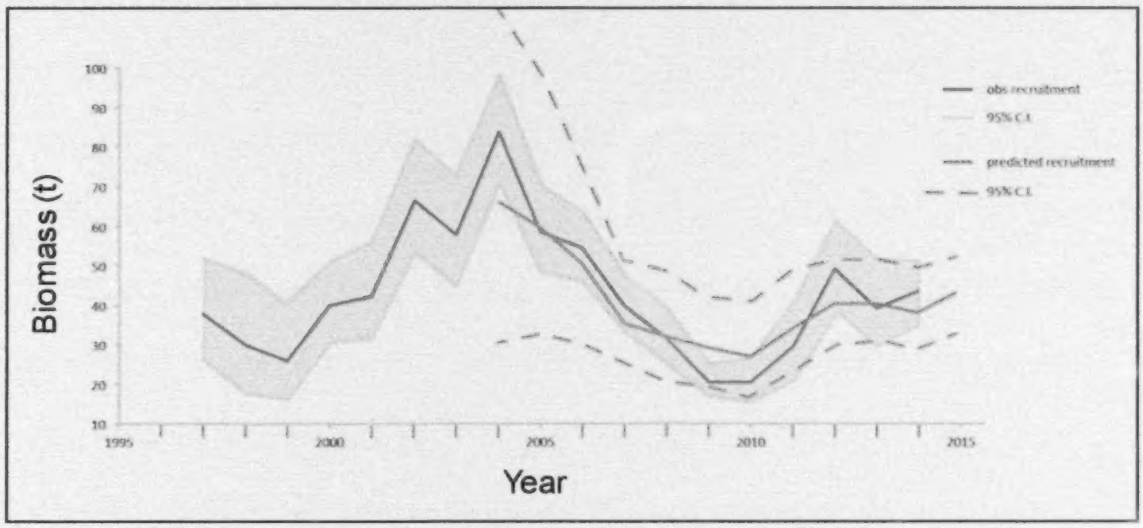

Figure 7. Comparison between the observed (mean with 95% confidence intervals) and predicted (mean with 95% confidence intervals) recruitment (R-1) of male snow crab (Chionoecetes opilio) based on the Bayesian model on prerecruits (Surette and Wade 2006; Wade et al. 2014).

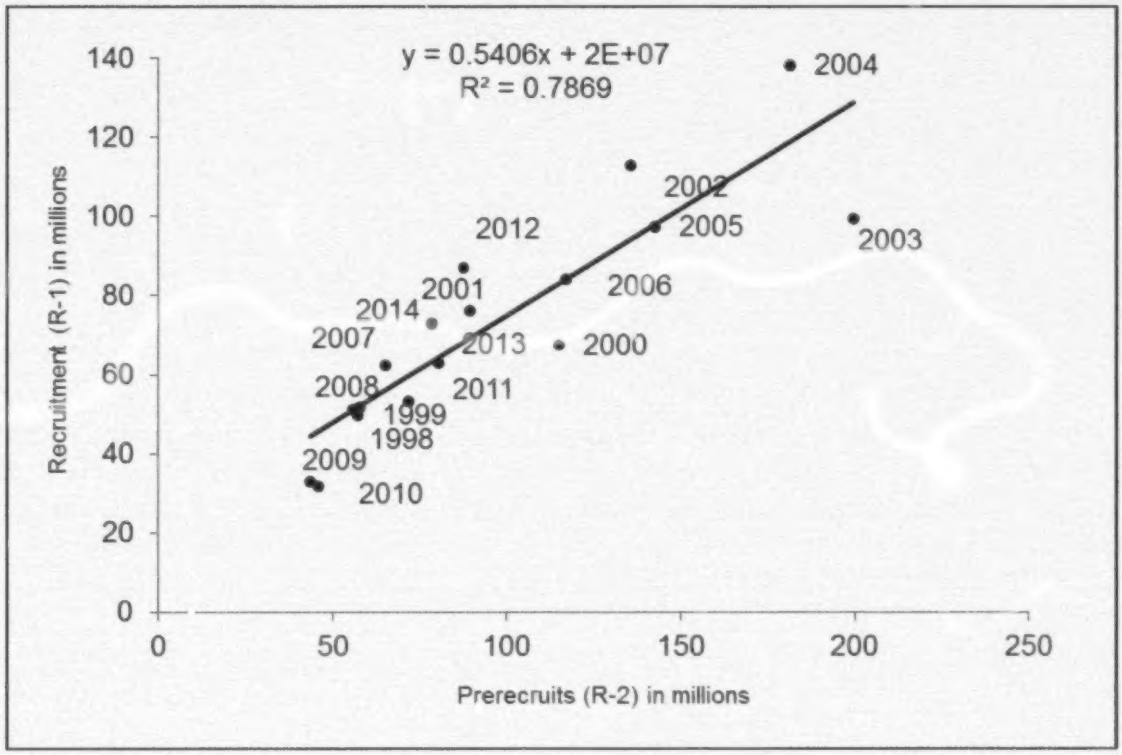

Figure 8. Relationship between the estimated abundance of prerecruits R-2 in year t and the estimated abundance of the recruitment to the fishery (R-1) in year t + 1 from the trawl survey data for the snow crab (Chionoecetes opilio) assessment in the southern Gulf of St. Lawrence.

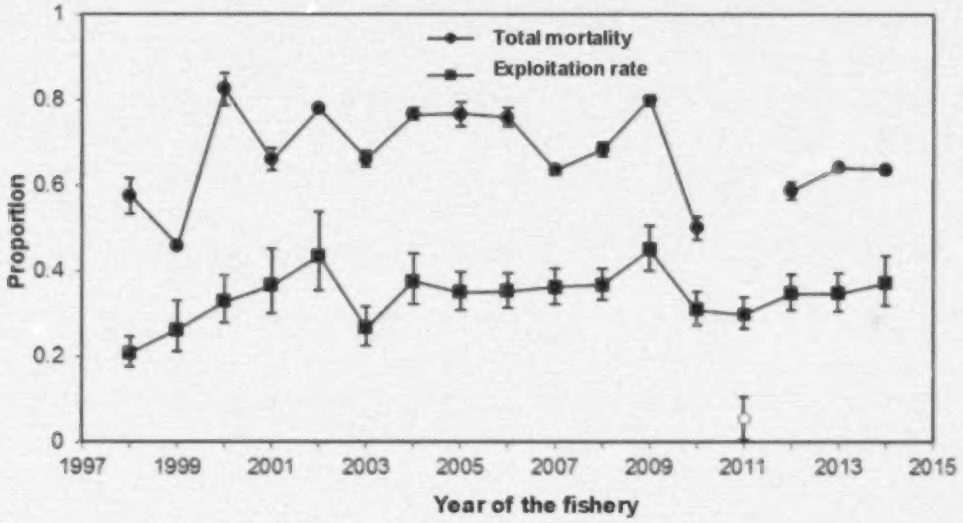

Figure 9. Estimated annual rates of exploitation and total loss of commercial-sized adult male snow crab (Chionoecetes opilio) in the southern Gulf of St. Lawrence, 1997 to 2014. The 2011 total mortality value is not reliable (Hébert et al. 2012).

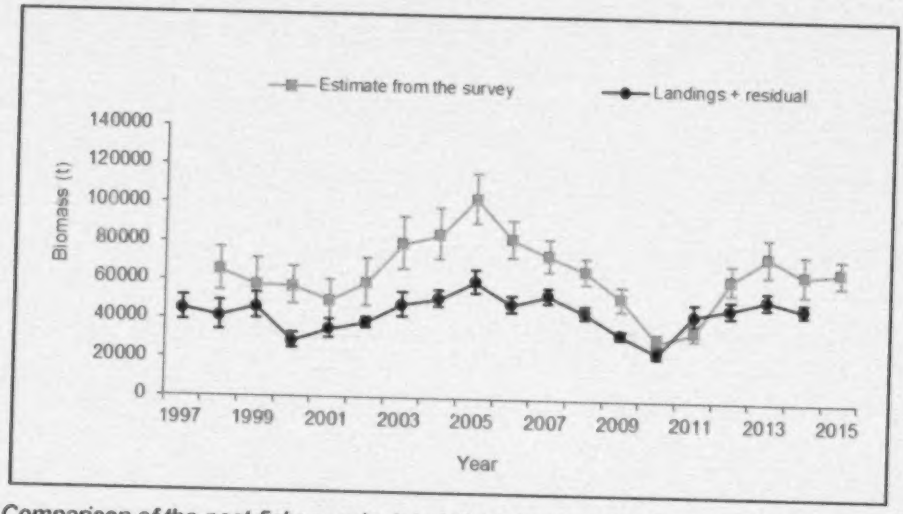

Figure 10. Comparison of the post-fishery calculated biomass (t; residual biomass plus the landings in year t+1) and the pre-fishery commercial-sized adult male snow crab (Chionoecetes opilio) biomass (t; recruitment plus residual biomass in year t) estimated from the trawl survey in the southern Gulf of St. Lawrence.

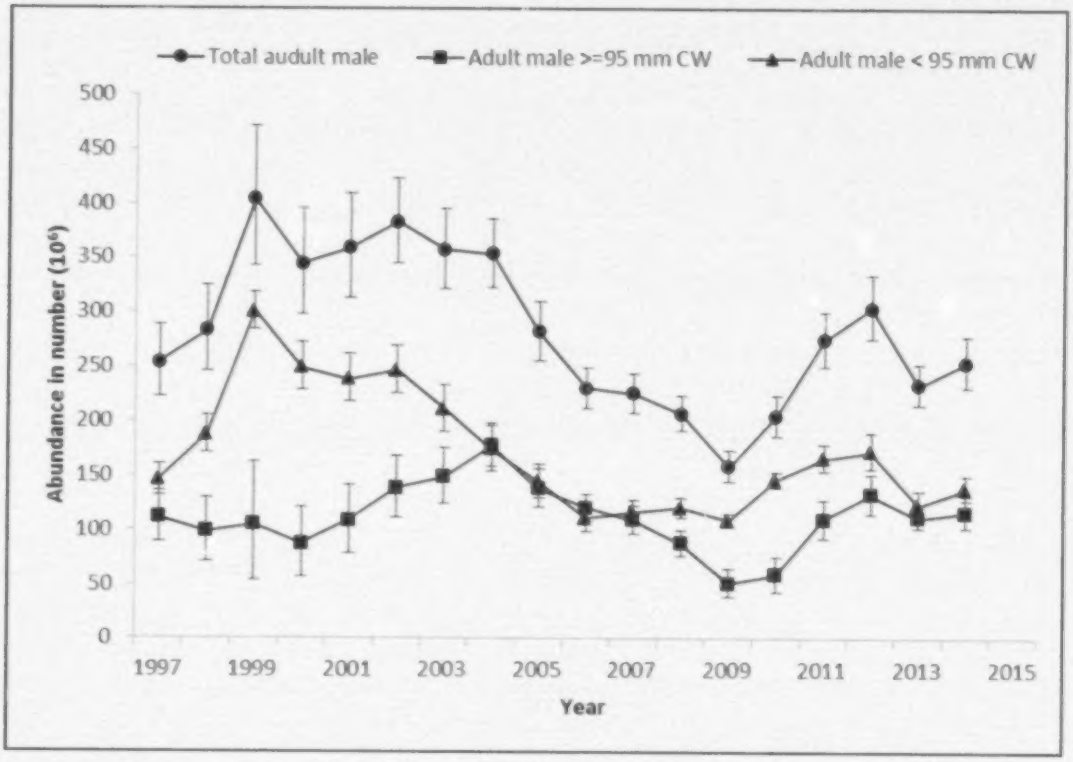

Figure 11. Estimated abundance (number in millions) of snow crab (Chionoecetes opilio) adult males in the southern Gulf of St. Lawrence, 1997 to 2014. CW = Carapace width.

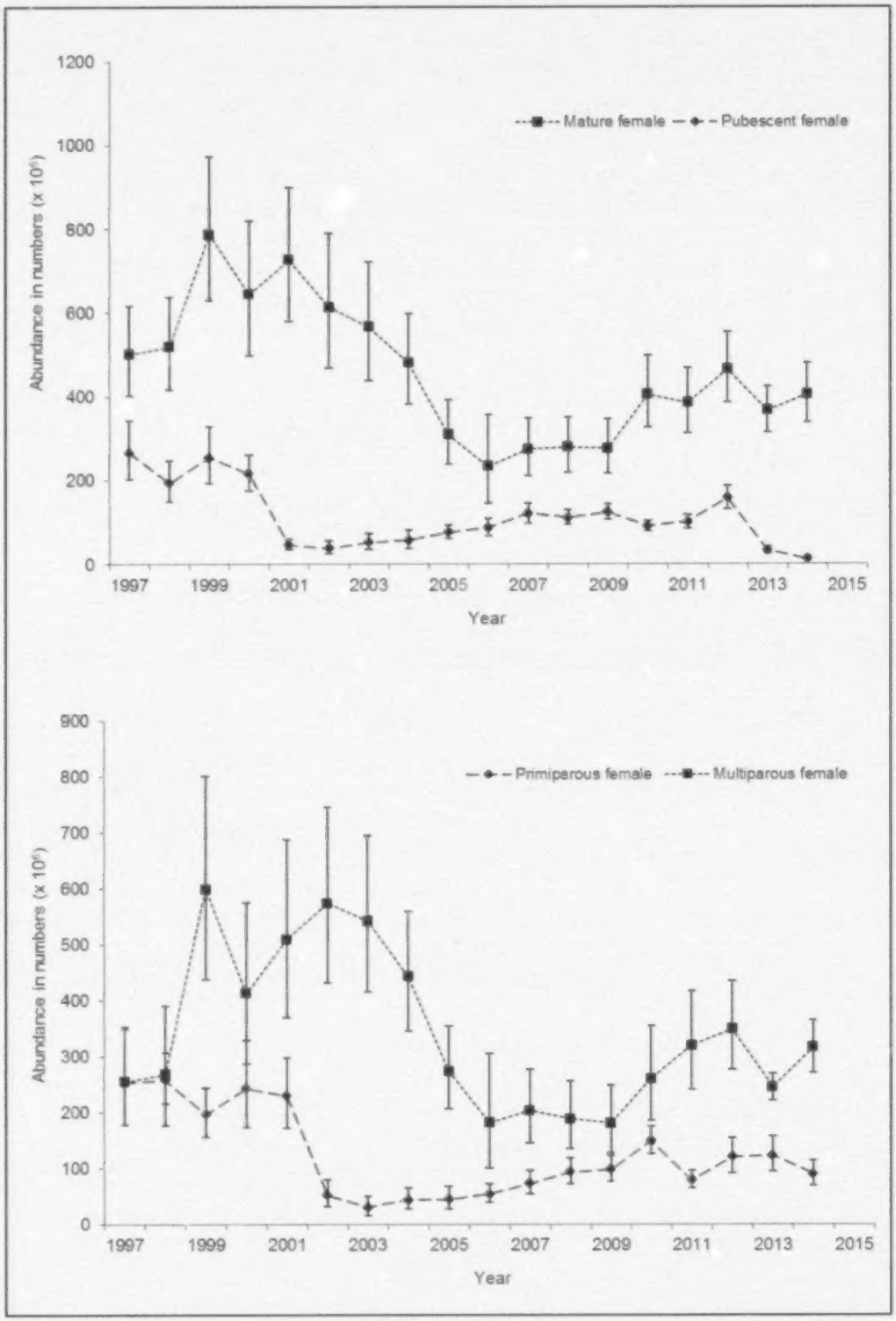

Figure 12. Abundance (number in millions) of pubescent, primiparous, multiparous and mature snow crab (Chionoecetes opilio) females in the southern Gulf of St. Lawrence, 1997 to 2014.

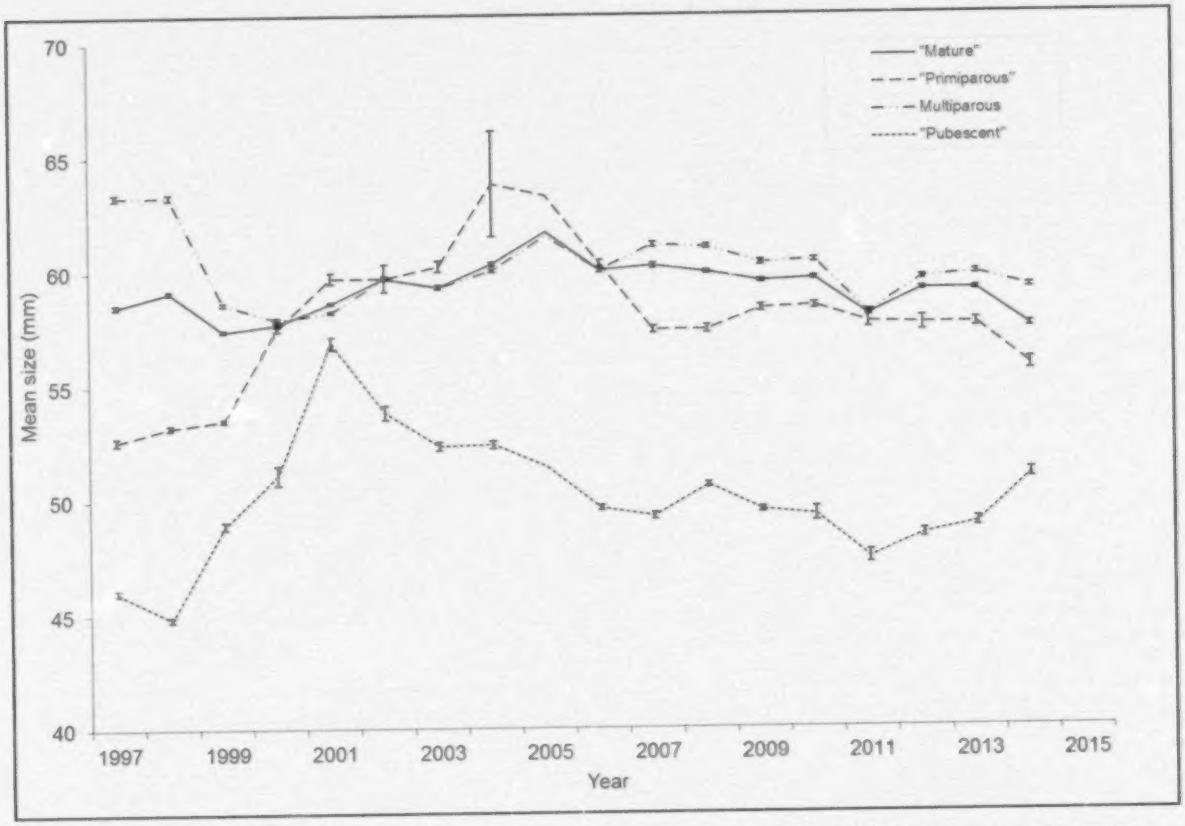

Figure 13. Mean size (carapace width in mm) with standard errors of pubescent, primiparous, multiparous and mature snow crab (Chionoecetes opilio) females based on samples from the trawl surveys, 1997 to 2014.

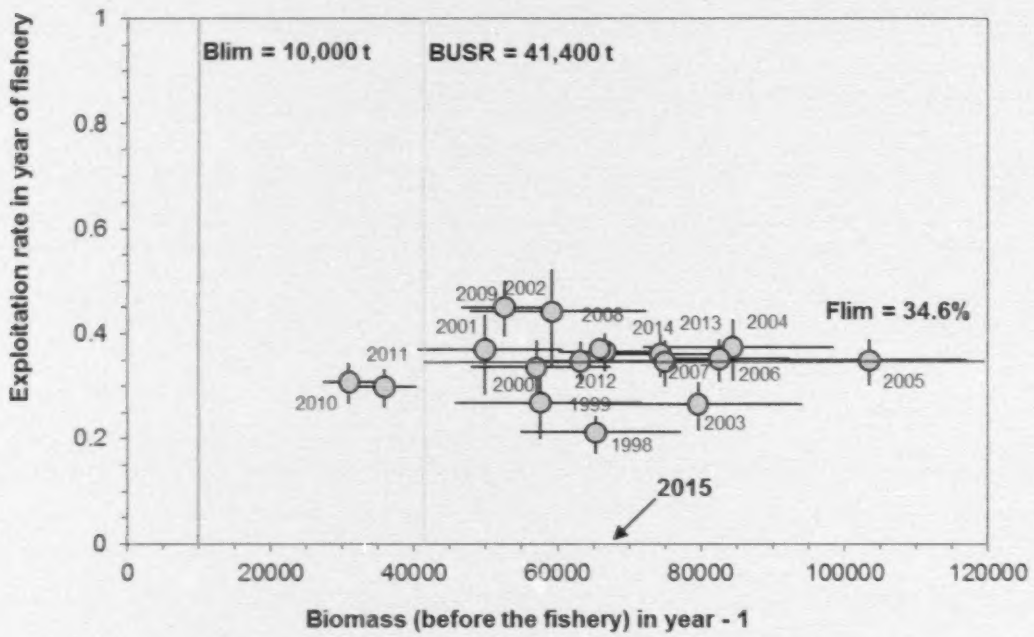

Figure 14. Trajectory of stock abundance (biomass of commercial-sized adult male snow crab (Chionoecetes opilio) as estimated from the trawl survey in year t – 1 versus exploitation rate of this biomass in the fishery of year t. Year of the fishery is labelled on the figure. B_{lim} = The limit reference point for biomass; Flim = Fishing removal rate limit reference point; B_{USR} = The upper stock reference point.

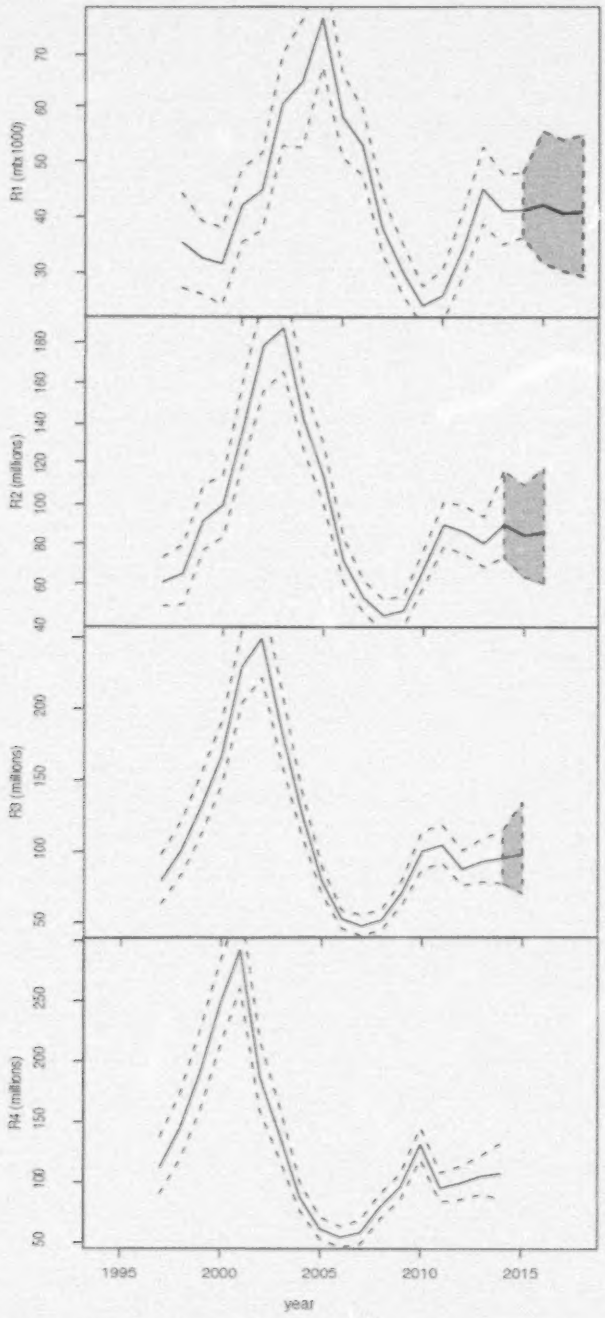

Figure 15. Snow crab (Chionoecetes opilio) recruitment (R) abundance (mean with 95% confidence intervals) by pre-recruit stages (Rj), where j =1,...,4 years until recruitment to the fishery based on the survey data estimates. Shaded areas are forecasted abundance from the Bayesian model (Surette and Wade 2006).

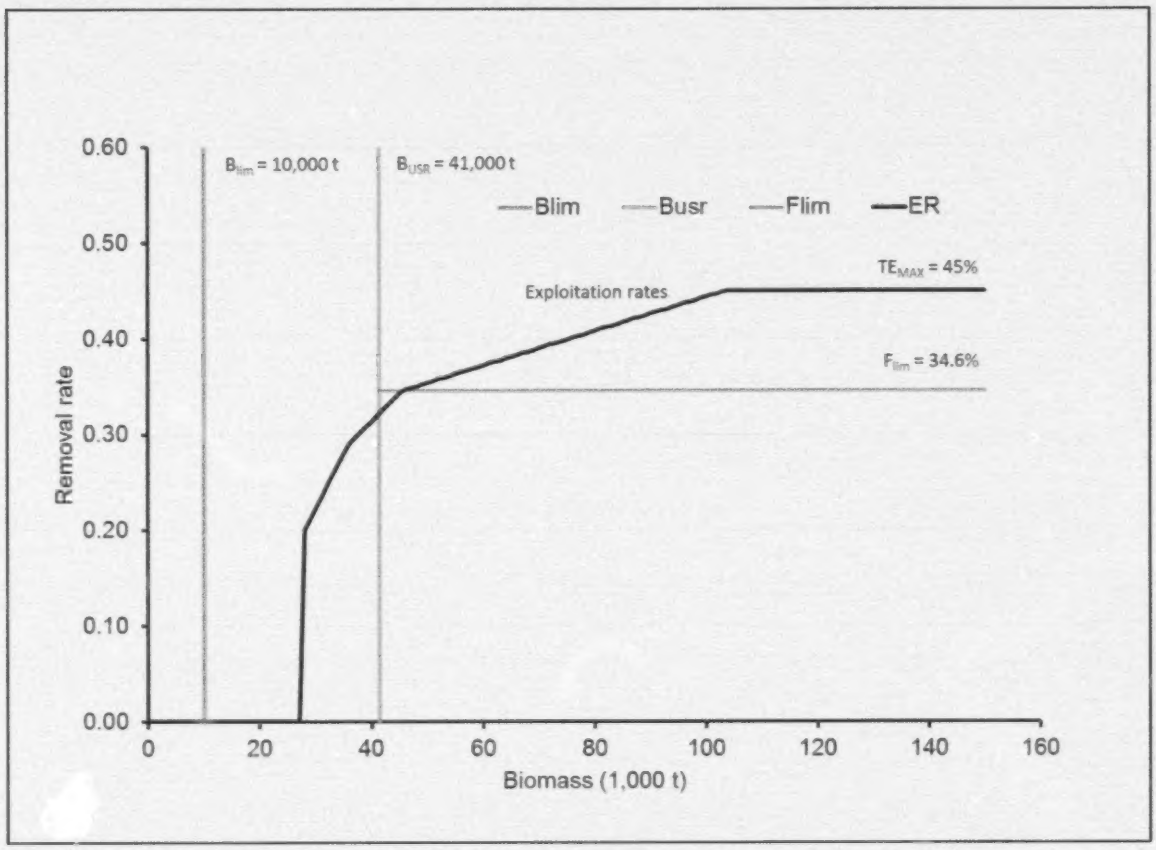

Figure 16. Harvest proportional decision rule (variant 4) compliant with the precautionary approach for the southern Gulf of St. Lawrence snow crab (Chionoecetes opilio) fishery (DFO 2014b). B_{lim} = The limit reference point for biomass; F_{lim} = Fishing removal rate limit reference point; B_{USR} = The upper stock reference point; ER = The exploitation rates based on the proportional harvest decision rule (variant 4).

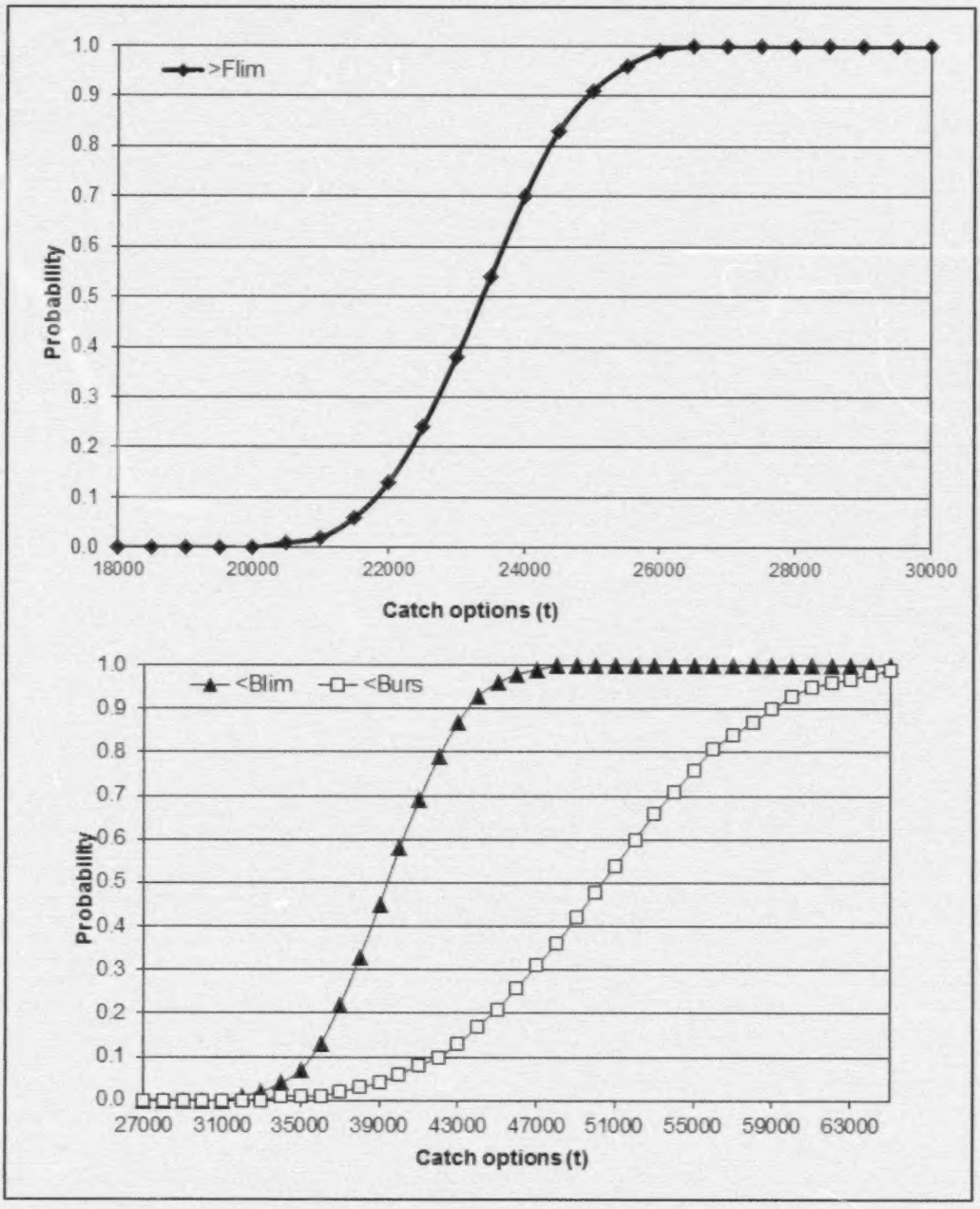

Figure 17. Risk analysis of catch options (t) for the 2015 fishery based on the expanded polygon for the southern Gulf of St. Lawrence snow crab, Chionoecetes opilio, showing probabilities of exceeding the fishing removal rate limit reference point (F_{lim}), of the hard-shelled commercial-sized adult male remaining biomass in 2015 falling below the limit reference point for biomass (B_{lim}) and of the commercial-sized adult male biomass in 2015 will be below the upper reference point (B_{USR}) after the 2015 fishing season.

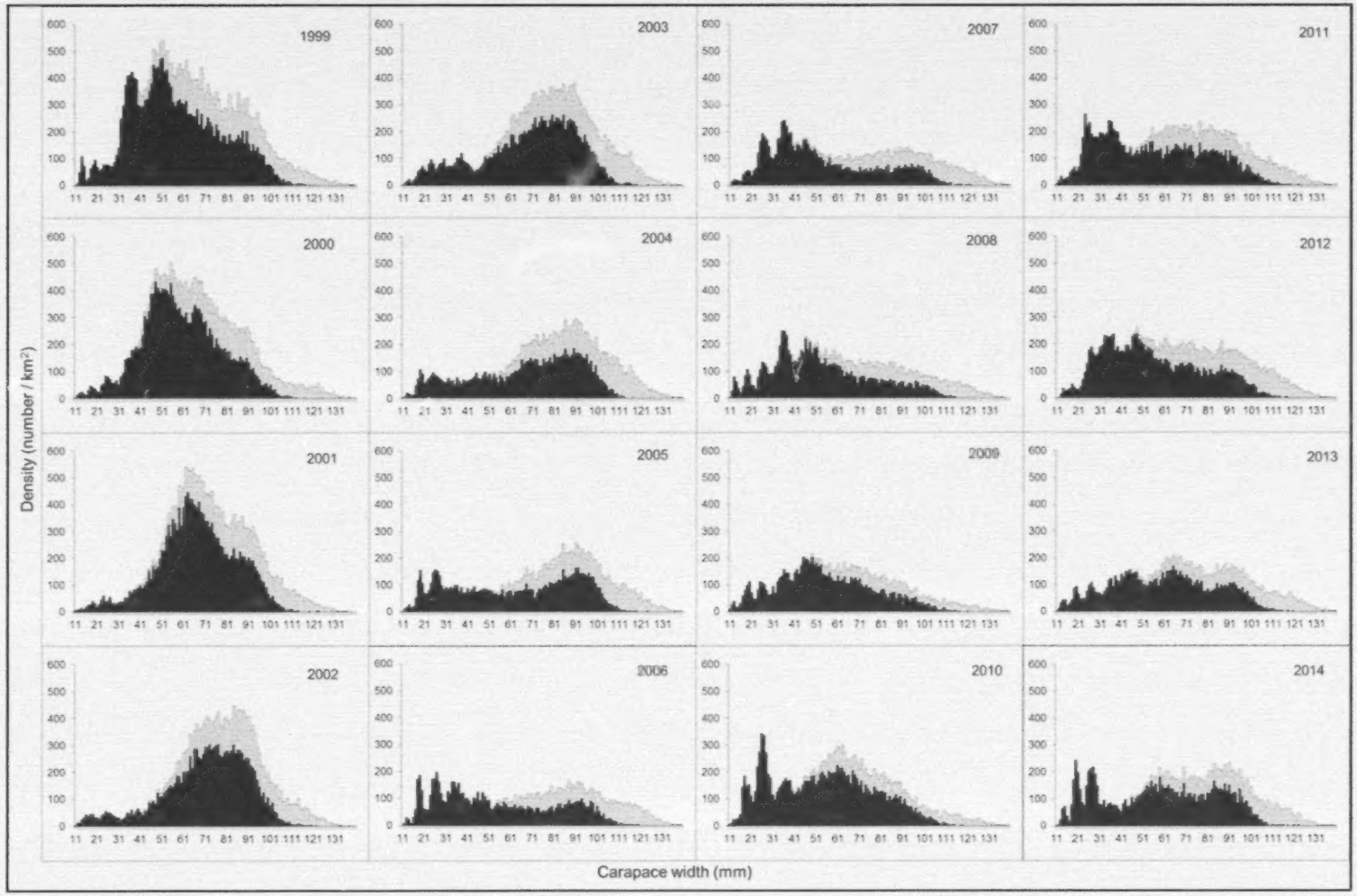

Figure 18. Size frequency distributions (by 1 mm carapace width interval) for male snow crabs (white bars are adult males and black bars are adolescent males) based on samples from the post-fishery trawl surveys in the southern Gulf of St. Lawrence, 1999 to 2014. These size frequency distributions represent the mean number of male snow crab (Chionoecetes opilio) per km^2 based directly on samples in the trawl survey.

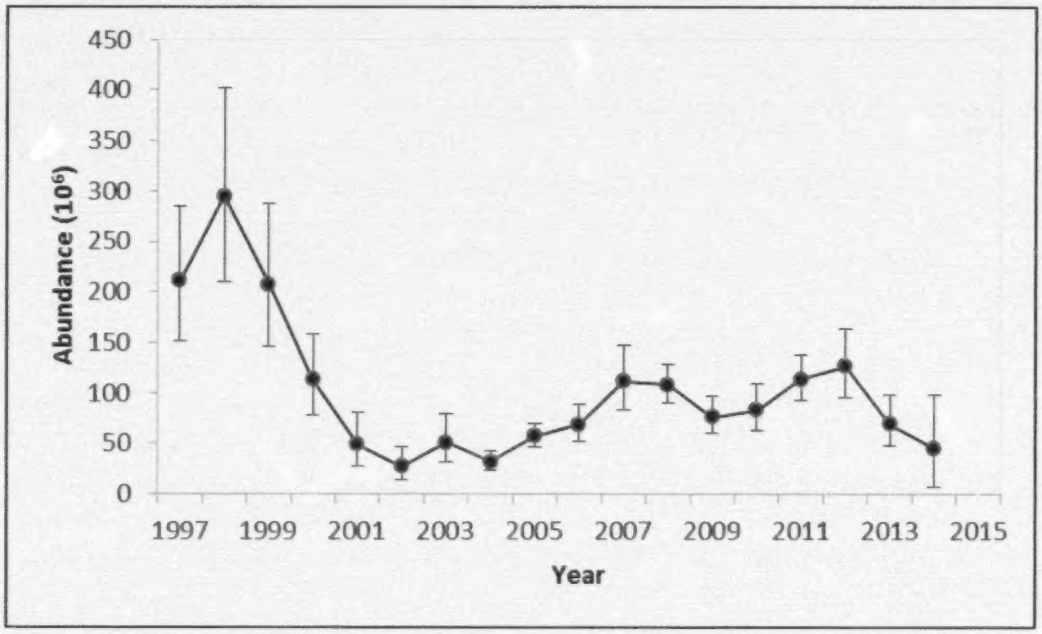

Figure 19. Abundance indices of small adolescent male snow crab (Chionoecetes opilio) with carapace width between 34 to 44 mm estimated from the trawl survey data in the southern Gulf of St. Lawrence, 1997 to 2013. These are crabs which reach legal size in approximately 6 years.

Figure 20. Density (number per km²) contours of adolescent male snow crab, (Chionoecetes opilio), ≥ 56 mm of carapace width, based on the trawl surveys conducted in the southern Gulf of St. Lawrence, 2003 to 2014.

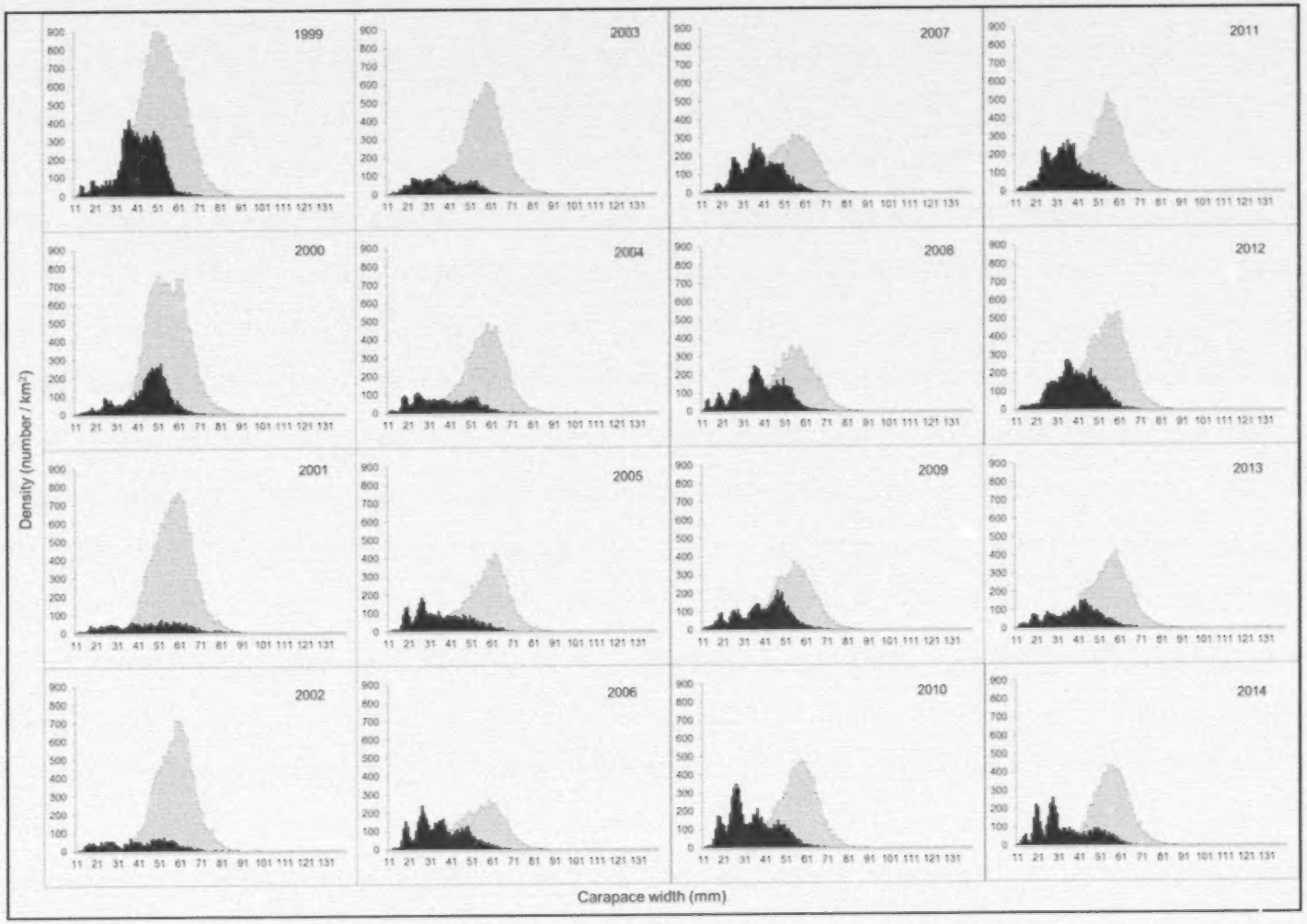

Figure 21. Size frequency distributions (carapace width by 1 mm interval) for female (white bars are mature females and black bars are pubescent and immature females) snow crab (Chionoecetes opilio) based on samples from the post-fishery trawl surveys in the southern Gulf of St. Lawrence, 1999 to 2014. These size frequency distributions represent the mean number of female crab per km^2 directly based on samples in the trawl survey.